

**FINAL REPORT—ARSENIC REMOVAL
DEMONSTRATION PROJECT
MINE WASTE TECHNOLOGY PROGRAM
ACTIVITY III, PROJECT 9**

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Federal Energy Technology Center
Pittsburgh, Pennsylvania 15236
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FINAL REPORT—ARSENIC REMOVAL DEMONSTRATION PROJECT

MINE WASTE TECHNOLOGY PROGRAM ACTIVITY III, PROJECT 9

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Foreword

Today, the mineral industries are developing and modifying technologies that will enable industries to operate more efficiently. If improperly dealt with, the waste generated by these industries can threaten public health and degrade the environment. The U.S. Environmental Protection Agency (EPA) is charged by the Congress of the United States with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the EPA strives to formulate and implement actions leading to a balance between human activities and the ability of natural systems to support and nurture life. These laws direct the EPA to perform research to define, measure the impacts, and search for solutions to environmental problems.

The National Risk Management Research Laboratory (NRMRL) of EPA is responsible for planning, implementing, and managing research, development, and demonstration programs to provide an authoritative, defensible engineering basis in support of the policies, programs, and regulations of the EPA with respect to drinking water, wastewater, pesticides, toxic substances, solid and hazardous wastes, and Superfund-related activities. The Federal Energy Technology Center (FETC) of the U.S. Department of Energy (DOE) has responsibilities similar to the NRMRL in that FETC is one of several DOE centers responsible for planning, implementing, and managing research and development programs. This document is a product of the research conducted by these two Federal organizations.

This document is the final report for EPA's Mine Waste Technology Program (MWTP) Activity III, Project 9, Arsenic Removal Demonstration Project. The MWTP is a program developed through an Interagency Agreement between EPA and DOE. MSE Technology Applications, Inc. manages the MWTP and is responsible for the field demonstration activities and preparing this document. The information generated under this program provides a vital communication link between the researcher and the user community.

One of the objectives of the MWTP is to identify the types of mining wastes impacting the nation and the technical issues that need to be addressed. Other objectives of this program are: 1) address these technical issues through application of treatment technologies, 2) determine the candidate technologies that will be tested and evaluated, and 3) determine the candidate waste form/sites where these evaluations will take place.

Executive Summary

This document is the final report for the U.S. Environmental Protection Agency's (EPA) Mine Waste Technology Program (MWTP) Activity III Project 9, Arsenic Removal Demonstration Project. The MWTP is a program developed through an Interagency Agreement (IAG) between EPA and the U.S. Department of Energy (DOE). MSE Technology Applications, Inc. (MSE) manages the MWTP and owns/operates the MSE Testing Facility in Butte, Montana, previously the DOE-Western Environmental Technology Office. MSE proposed and was granted funding for the Arsenic Removal Demonstration Project during the December 1996 IAG Management Committee Meeting.

Acidic, metal-bearing water draining from remote abandoned mines has been identified by the EPA as a significant environmental/health hazard in the Western United States. Many of these waters contain dissolved arsenic in the trivalent and pentavalent state. The arsenic problems in discharge streams are directly related to the EPA's Technical Issue *Mobile Toxic Constituents—Water*. The National Drinking Water Standard for arsenic is 50 parts per billion (ppb). The World Health Organization revised the guideline for arsenic in drinking water from 50 to 10 ppb in 1993.

The purpose of the Arsenic Removal Demonstration Project was to demonstrate alternative treatment technologies capable of removing arsenic from mineral industry effluents to below 50 ppb. Several technologies with potential application to treat arsenic problems were presented in the MWTP Activity I, Volume 5, *Issues Identification and Technology Prioritization Report—Arsenic*. Each technology was screened and prioritized on the basis of its potential to reduce arsenic levels in the mineral industry. Two innovative technologies were selected, Mineral-Like Precipitation and Alumina Adsorption with Microfiltration. Both technologies were demonstrated/evaluated by treating two of the same industrial effluents, industrial process water and arsenic-contaminated mine water. The Ferrihydrite Adsorption technology, EPA's Best Demonstrated Available Technology (BDAT) for removal of arsenic, was used for comparative purposes.

In January 1997, MSE prepared agreements with Montana Tech of the University of Montana (Montana Tech) and ZENON Environmental, Inc. (ZENON). These agreements were signed for the demonstration/evaluation of their Mineral-Like Precipitation and Alumina Adsorption with Microfiltration technologies respectively. Four Montana Tech employees and two ZENON employees, in collaboration with MSE staff, performed the pilot-scale demonstrations in July–September 1997. This report addresses the results of the pilot demonstration projects and the subsequent leachability testing of the arsenical residues produced during the demonstration.

Technology Demonstrations

Mineral-Like Precipitation

The concept of this process is to strip arsenic from solutions in such a manner so as to produce mineral-like precipitated salts that are stable for long-term storage in outdoor pond-type environments. This process was developed by the Principal Investigator, Dr. Larry Twidwell, and may be accomplished by precipitation from solutions containing arsenate and phosphate. The concept was to substitute arsenate into an apatite structure $[\text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2]$ thereby forming a solid solution

compound $[\text{Ca}_{10}(\text{As}_x\text{P}_y\text{O}_4)_6(\text{OH})_2]$ that would be thermodynamically stable in an outdoor storage environment.

Alumina Adsorption

Alumina adsorption technology uses aluminum oxide to adsorb arsenic onto its surface from arsenic-bearing solutions. The process is completed at a certain pH range. After absorption, reagents are added to the alumina to desorb the arsenic from the solid into a concentrated brine. The concentrated arsenic brine solution is then treated using an iron adsorption technology to remove and stabilize the arsenic. The activated alumina in the process is recycled following the desorption process where it is treated with a strong caustic solution of sodium hydroxide.

Ferrihydrite Adsorption

Ferrihydrite technology is an industrial technique commonly used for dissolved heavy metal removal and, as stated earlier, is EPA's BDAT for arsenic removal. For ferrihydrite adsorption to occur, the ferric iron (Fe^{+3}) must be present in the water to be treated. Dissolved arsenic is removed by a lime neutralization process in the presence of the ferric iron, which results in the formation of arsenic-bearing hydrous ferric oxide (ferrihydrite).

Waste Stream Description

Potential waste streams were identified and prioritized in the MWTP Activity I, Volume 5, Appendix A, Issues Identification and Prioritization for Arsenic. The arsenic removal demonstration was designed to demonstrate arsenic removal technologies that are capable of removing arsenic to below the federal discharge standards of 50 ppb. Three different waters were treated, e.g., ASARCO's lead smelter scrubber blowdown water [containing > 3 grams per liter (g/L) arsenic and many other associated metals], ASARCO's water treatment thickener overflow water [containing ~ 6 parts per million (ppm) arsenic], and TVX Mineral Hill Mine 1,300' Portal groundwater (containing ~ 500 ppb arsenic).

Demonstration Results

All three addressed technologies (ferrihydrite adsorption, alumina adsorption, and mineral-like precipitation) showed favorable results for arsenic removal using groundwater; however, using industrial process wastewater, only two of the technologies (Mineral-Like Precipitation and Ferrihydrite Adsorption) were capable of removing arsenic to below necessary discharge standards. The complex chemistry of the industrial wastewater had a profound effect on arsenic removal using alumina adsorption.

Mineral-Like Precipitation

Mineral-Like Precipitation removed significantly more of the arsenic in each of the demonstrations than the stated goal of the project [i.e., to lower the arsenic content in the effluent water to less than the drinking water standard for arsenic (< 50 ppb)]. In fact, the final arsenic content in the effluent waters was in most cases < 10 ppb. A summary of the results for each demonstration is presented in Table ES-1.

Table ES-1. Mineral-Like Precipitation Results

System	Description	[As] Concentration	
		Inlet Water	Effluent Water
ASARCO Scrubber Blowdown Water	P/As~ 5.5, 1,665 gallons treated	~ 3.3 g/L	7-9 Fg/L
ASARCO Scrubber Blowdown Water	P/As~ 12, 405 gallons treated	~ 3.3 g/L	6-9 Fg/L
ASARCO Thickener Overflow Water	P/As~ 10, 1,185 gallons treated	~ 5.8 mg/L	6-15 Fg/L
ASARCO Thickener Overflow Water	P/As~ 100, 1,425 gallons treated	~ 5.8 mg/L	3-13 Fg/L
Mineral Hill Mine 1,300' Portal Groundwater	P/As~ 10, 1,185 gallons treated	420 Fg/L	6-7 Fg/L
Mineral Hill Mine 1,300' Portal Groundwater	P/As~ 20, 3,915 gallons treated	450 Fg/L	4-7 Fg/L

Alumina Adsorption

Alumina adsorption technology was very successful in removing arsenic when treating TVX's Mineral Hill Mine 1,300' Portal groundwater (containing ~ 500 ppb arsenic). Treating ASARCO's lead smelter thickener overflow water (containing ~ 6.0 mg/L arsenic and many other associated metals) with this technology is ineffective. Other species (e.g., sulfate) competed and interfered with available alumina adsorption sites. A summary of the results for each demonstration is presented in Table ES-2.

Table ES-2. Alumina Adsorption Results

System	[As] Concentration	
	Inlet Water	Effluent Water
ASARCO Thickener Overflow Water (60 g/L Activated Alumina)	~ 6.0 g/L	~ 200 mg/L
Mineral Hill Mine 1,300' Portal Groundwater	450 Fg/L	21 Fg/L

Ferrihydrite Adsorption

Ferrihydrite adsorption technology was successful in treating both of the demonstration waters. Using an iron/arsenic mole ratio of 8 produced adequate results; however, the arsenic drinking water discharge standard of less than 50 ppb was never achieved treating the thickener overflow water. Increasing the iron to arsenic mole ratio to 10 when treating both the thickener overflow water and the Mineral Hill Mine 1,300' Portal groundwater lowered arsenic concentrations to less than discharge standards. A summary of the results for each demonstration is presented in Table ES-3.

Table ES-3. Ferrihydrite Adsorption Results

System	[As] Concentration	
	Inlet Water	Effluent Water
ASARCO Thickener Overflow Water (Iron to Arsenic Mole Ratio = 8)	6.0 mg/L	~ 100 Fg/L
ASARCO Thickener Overflow Water (Iron to Arsenic Mole Ratio = 10)	6.0 mg/L	~ 20 Fg/L
Mineral Hill Mine 1,300' Portal Groundwater	450 Fg/L	< 50 Fg/L

Economic Evaluation

One objective of this study was to perform a first-order cost estimate for the developed treatment flowsheets. Therefore, a “first-order” cost estimate was performed. The cost estimate presented here is not a detailed engineering cost analysis. It is a first-order cost estimate that should be within $\pm 30\%$.

Table ES-4. Economic Evaluation for Selected Technologies Treating Groundwater with 500 ppb Arsenic at 300 gpm.

	Mineral-Like Precipitation	Alumina Adsorption	Ferrihydrite Adsorption
Capital	\$250,000 \pm 75,000	\$396,000 \pm 118,8000	\$250,000 \pm 75,000
Operations and Maintenance per Year	\$41,080	\$130,700	78,904
Operations and Maintenance per 1,000 gallons treated	\$0.30 +/- 0.09	\$0.70 +/- 0.30	\$0.55 +/- 0.16

Acknowledgments

This document, the Arsenic Removal Demonstration Project Final Report, was prepared for the U.S. Environmental Protection Agency (EPA) National Risk Management Research Laboratory (NRMRL) in Cincinnati, Ohio, and the U.S. Department of Energy (DOE) Federal Energy Technology Center (FETC) in Pittsburgh, Pennsylvania, by MSE Technology Applications, Inc. (MSE) under contract DE-AC22-96EW96405. The Arsenic Removal Demonstration Project was conducted under the Mine Waste Technology Program (MWTP) funded by the EPA. The MWTP was jointly administered by EPA and DOE through an Interagency Agreement. MSE manages the MWTP and owns/operates the MSE Testing Facility in Butte, Montana, previously the DOE Western Environmental Technology Office.

Mr. Roger Wilmoth from NRMRL served as EPA's MWTP Program Manager, and Mr. Melvin Shupe from DOE served as DOE's Technical Program Officer. Mr. Creighton Barry served as MSE's Program Manager, Dr. Martin Foote served as MSE's MWTP Project Manager, and Mr. Jay McCloskey served as MSE's Technical Project Manager. Dr. Larry Twidwell from Montana Tech of the University of Montana (Montana Tech) and Mr. Glenn Vicevic from ZENON Environmental Inc. acted as technology providers and are recognized for their contributions. Dr. Twidwell was the developer of the Mineral-Like Precipitation Process and represented Montana Tech during the demonstration evaluation process. Mr. Vicevic represented ZENON, Inc. Both Dr. Twidwell and Mr. Vicevic provided engineering expertise before and during the demonstrations. In addition, both prepared demonstration reports for their respective technologies. The organization and execution of the MWTP Arsenic Removal Demonstration Project was a collaborative effort between the participants mentioned above.

In addition to the people listed above, the following agency and contractor personnel contributed their time and energy by participating in the Arsenic Removal Demonstration Project and preparing this document.

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Acronyms, Abbreviations, and Chemical Symbols

AA	atomic absorption
AAM	arsenic adsorption microfiltration
AHAP	arsenatehydroxyapatite
ANSTO	Australian Nuclear Science and Technology Organization
APHAP	arsenatephosphate hydroxyapatite
As	arsenic
As(III)	arsenic(III), arsenite
As(V)	arsenic(V), arsenate
BDAT	best demonstrated available technology
CCB	continuing calibration blank
CCV	continuing calibration verification
cm	centimeter
COC	chain-of-custody
CRC	Cooperative Research Centre for Waste Management and Pollution Control Limited
DI	deionized
DOE	U.S. Department of Energy
E_H	oxidation-reduction potential
EPA	U.S. Environmental Protection Agency
FCC	factored capital cost
Fe	iron
Fe(II)	iron(II), ferrous
Fe(III)	iron(III), ferric
FETC	Federal Energy Technology Center
FIT	flow indicating transmitter
g	grams
g/L	grams per liter
gpm	gallons per minute
H_2O_2	hydrogen peroxide
HAP	hydroxyapatite
HCl	hydrochloric acid
HPDE	high-density polyethylene
IAG	Interagency Agreement
ICP	inductively coupled plasma
ICP-AES	inductively coupled plasma atomic emission spectroscopy
L	liter
LCS	laboratory control sample
M	million
M&S	Marshall and Swift
MDL	method detection limit
mg/L	milligrams per liter
mL	milliliter
Montana Tech	Montana Tech of the University of Montana

Acronyms, Abbreviations, and Chemical Symbols (cont.)

MSE	MSE Technology Applications, Inc.
MT/hr	metric ton per hour
mV	millivolts
MWTP	Mine Waste Technology Program
NIST	National Institute of Standards and Technology
NPV	net present value
NRMRL	National Risk Management Research Laboratory
ppb	parts per billion
ppm	parts per million
psig	pounds per square inch gauge
QA	quality assurance
QA/QC	quality assurance/quality control
QAPP	quality assurance project plan
QC	quality control
RPD	relative percent difference
SOP	Standard Operating Procedure
TCLP	toxicity characteristic leaching procedure
TSS	total suspended solids
XPS	X-ray photoelectron spectrometry
ZENON	ZENON Environmental, Inc.
Fg/L	micrograms/liter
Fm	micrometer

1. Introduction

1.1 Project Management

This document is the Final Report for the U.S. Environmental Protection Agency's (EPA) Mine Waste Technology Program (MWTP) Activity III Project 9, Arsenic Removal Demonstration Project. The MWTP is a program developed through an Interagency Agreement (IAG) between EPA and the U.S. Department of Energy (DOE) (Ref. 1). MSE Technology Applications, Inc. (MSE) implements the MWTP and owns/operates the MSE Testing Facility in Butte, Montana. MSE proposed and was granted funding for the Arsenic Removal Demonstration Project during the December 1996 IAG Management Committee Meeting.

1.2 Project Purpose

The purpose of the Arsenic Removal Demonstration Project was to demonstrate alternative water treatment technologies capable of effectively removing arsenic. Several technologies with potential application to treat water with arsenic problems were presented in the MWTP Activity I, Volume 5, *Issues Identification and Technology Prioritization Report—Arsenic* (Ref. 2). Each technology was screened and prioritized on the basis of its potential to reduce arsenic levels within arsenic containing waste streams.

1.3 Quality Assurance

The analytical methods and pilot-scale treatment testing conducted for this study were consistent with EPA's requirements outlined in the project-specific MWTP Activity III, Project 9 Quality Assurance Project Plan (QAPP) for the Arsenic Removal Project Demonstration (Ref. 3). The QAPP followed the EPA Category II procedures.

This final report describes the research that was conducted and summarizes the technical results that were obtained by evaluating the arsenic removal treatment technologies from mineral industry arsenic-bearing waters.

1.4 Technical Developers

1.4.1 Mineral-Like Precipitation

Mineral-like precipitation has been extensively investigated at the bench-scale by Dr. Larry Twidwell, a Montana Tech of the University of Montana (Montana Tech) professor. The research has been performed over a 10-year period on several different arsenic-bearing waters.

1.4.2 Alumina Adsorption with Microfiltration

Alumina adsorption is a widely recognized technology for the removal of arsenic from water. An innovative approach using alumina adsorption combined with microfiltration has been developed by ZENON Environmental, Inc. (ZENON) of Canada.

1.5 Scope of the Problem

Acidic, metal-bearing water draining from remote, abandoned mines has been identified by the EPA as a significant environmental/health hazard in the Western United States (Ref. 4). Many of these waters contain dissolved arsenic in the trivalent and pentavalent state.

Arsenic compounds and solutions are frequently an unwanted byproduct of the mining and metallurgical extraction of metals such as copper, gold, lead, and nickel. Arsenic waste problems will continue to grow as high-grade ores with low-arsenic content are depleted, and the processing of sulfide ores

with high arsenic content becomes increasingly common. An example of arsenic-bearing solid wastes from the processing of gold and base metal ores is the flue dust produced from roasting and smelting unit operations. The flue dust is often concentrated in arsenic; the arsenic is usually present as arsenic trioxide. Large quantities of flue dust from past and current mineral-processing operations are being kept in temporary storage pending the development of safe disposal methods.

The U.S. National Drinking Water Standard for arsenic is 50 parts per billion (ppb). Due to concerns for cancer risk associated with arsenic, the World Health Organization recently revised the guideline for arsenic in drinking water from 50 to 10 ppb in 1993 (Ref. 5).

Arsenic is a naturally occurring element commonly found in the mining industry. Dissolved arsenic has two common valence states (III and V). Generally, arsenic in the arsenite state (III) is more soluble than arsenic in the arsenate state (V). Due to this chemical trait, arsenic is generally removed more effectively from solutions in the oxidized or arsenate state (Ref. 6).

1.6 Statement of Project Objectives

The primary objective of the field demonstration project was to assess the

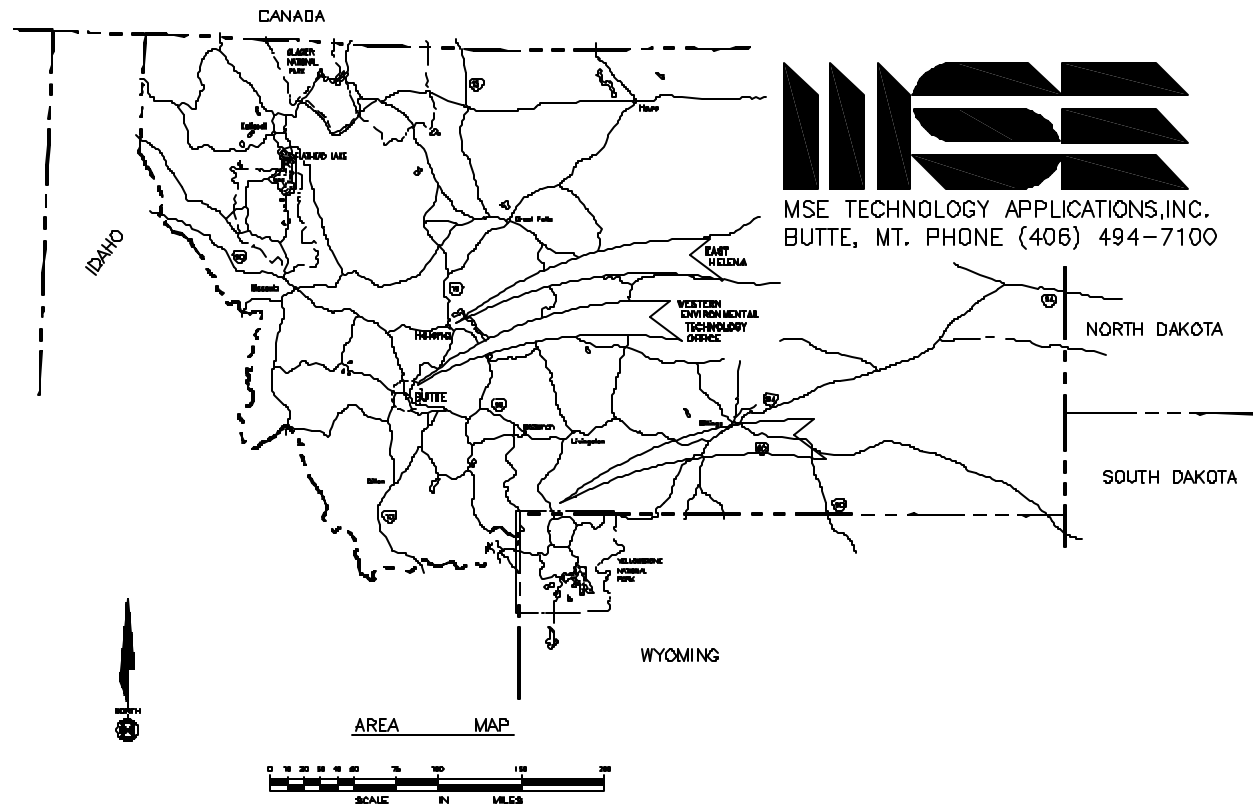
effectiveness of the chosen processes for removal of arsenic from solution. Another objective of the project was to evaluate the products formed from each process to determine if they are environmentally stable. More specifically, the project objectives were:

- C Reduction of the concentration of dissolved arsenic in the effluent waters to a level less than the National Primary Drinking Water Regulation Limit for arsenic established by the EPA of 50 ppb, or reduce the concentration of dissolved arsenic by 50% if the influent concentration was less than 50 ppb.
- C Production of the concentrated arsenic-bearing solids from the processes that are environmentally stable by demonstrating that arsenic results using TCLP will be below the maximum concentration for toxicity of 5.0 mg/L.

1.7 Demonstration Site Locations

A number of sites that have arsenic present in process or effluent streams were identified. Two sites selected for the demonstration were ASARCO Lead Smelter East Helena, Montana and TVX Mineral Hill Mine 1,300' Portal located in Jardine, Montana. Each site along with MSE in Butte, Montana is identified in Figure 1-1.

WESTERN ENVIRONMENTAL TECHNOLOGY OFFICE



ACAD# A85RD504

Figure 1-1. Site location map.

2. Project Organization and Responsibilities

2.1 Project Officers

Specific EPA, DOE, and MSE project officers and their respective responsibilities for Activity III, Project 9 are listed below.

EPA Project Officer—Roger Wilmoth: Responsible for EPA project management for MWTP and reviewing and approving the final project report.

DOE Project Officer—Mel Shupe: Responsible for DOE participation in the MWTP and reviewing and approving the final project report.

National Risk Management Research Laboratory (NRMRL) Quality Assurance Associate—Kim McClellan: Responsible for reviewing and approving the QAPP.

MSE Program Manager—Creighton Barry: Responsible for senior review of all project plans and deliverables and for ensuring that the project objectives are achieved within schedule and budget constraints.

MSE MWTP Projects Manager—Martin Foote: Responsible for ensuring that the project is conducted according to the appropriate plans and that all project activities are documented in a project file. Also informs the Program Manager of the project status and of any technical/administrative/contractual/ financial issues and proposed resolutions.

MSE Arsenic Removal Technical Project Manager—Jay

McCloskey: Responsible for the execution of elements assigned by the Project Manager. Directly responsible for the

execution of field experiments and sampling schedule.

MSE Project Test Engineer—Dick Harned: Responsible for developing the test plan for the project.

Montana Tech Representative—Dr. Larry Twidwell: Responsible for bench-scale testing of mineral-like precipitation process and scale up for the demonstration skid.

ZENON Representative—Glenn Vicevic: Responsible for construction and delivery of alumina adsorption skid to demonstration location, and input on experimental design related to ZENON skid.

MSE Technology Testing and Operations Manager—Vince Tonc: Responsible for all aspects of testing and operations including safety and health and QA/QC.

MSE Project QA Officer—Helen Joyce: Responsible for developing the project QAPP, auditing test personnel and equipment and for submitting audit findings to the Technology Testing and Operations Manager, and independent data validation.

MSE-HKM Laboratory Manager—Kevin Kissell: Responsible

for ensuring that all analytical data meets quality objectives and for review of all laboratory reports.

MSE-HKM Laboratory QA Officer—Jackie Timmer:

Responsible for reviewing all analytical data associated with the

project and submitting findings to the QA Manager.

3. Technology Descriptions

The three arsenic removal technologies demonstrated during the MWTP Activity III Project 9, Arsenic Removal Demonstration Project were 1) mineral-like precipitation; 2) alumina adsorption with microfiltration; and 3) ferrihydrite adsorption process.

At the request of the technology providers, minimal process information is provided in the following sections. Only sufficient information is provided to gain a basic understanding of each process.

3.1 Mineral-Like Precipitation of Arsenic

Mineral-like precipitation of arsenic from aqueous solution was investigated on a bench- scale level at Montana Tech by Dr. Larry Twidwell as part of MWTP Activity IV, Project 5—Removal of Arsenic from Waste Solutions as Storable Stable Precipitates (Ref. 7). The objective of this project was to strip arsenic from solutions in such a way so as to produce mineral-like precipitated products that are stable for long-term storage in outdoor pond environments. The approach investigated was the substitution of arsenate ions for phosphate ions in known phosphate minerals, such as hydroxy apatite $[\text{HAP}, \text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2]$ (Ref. 7). The mineral-like precipitation process is presented in Figure 3-1.

The MWTP Activity IV, Project 5 study resulted the following

positive results.

Arsenic can be effectively stripped to the parts per billion range from aqueous solutions by controlling the pH and P/As molar ratio in the initial solution.

A series of arsenatephosphate hydroxyapatite (APHAP)–bearing solid solutions can be formed by controlling the P/As molar ratio in the initial solution prior to precipitation. Solid solutions containing arsenic concentrations from approximately 3% to 30% have been formed. These are new compounds that have never been reported previously. The new compounds stoichiometry have been identified by chemical digestion and their structures by x-ray diffraction and x-ray photoelectron spectrometry (XPS).

The standard free–energy of formation of the APHAP compounds have been determined at 25E C. This information can be used to model the stability of the compounds under various solution conditions. One of the important considerations is whether the compounds will be stable for long-term storage in tailings pond environments (i.e., exposure to air). Previously, Dr. R.G. Robins had demonstrated that calcium arsenate compounds are unstable in air because the carbon dioxide in the air reacts with the calcium arsenate to form calcium carbonate and releases the arsenic back

to the solution phase (Ref. 8).

Modeling of tailings pond conditions shows that compound stability is a function of P/As mole ratio. Compounds with a P/As mole ratio greater than five should be stable to air exposure in tailings pond-type storage conditions.

Currently, compound stability is being tested by sparging air into stability tests were performed on sludge products from this demonstration.

If the long-term stability of the solids formed using the mineral-like precipitation process is demonstrated, this process shows great promise for industrial applications. The mineral-like precipitation process is illustrated in Figure 3-1. Sampling locations for the mineral-like precipitation process are also shown in Figure 3-1 [101, 102, 104, 105, 106 Filter cake #1, pH, and flow indicating transmitter (FIT)]. The same skid was used for both the ASARCO and Mineral Hill Mine demonstrations. The skid was thoroughly decontaminated following the ASARCO demonstration before transportation to the MSE Testing Facility to treat the Mineral Hill Mine water. The pH elements indicate the location of pH probes to monitor the pH in tank number 101, tank number 102, and tank number 103. The FIT element in Figure 3-1 denotes the location of a flow totalizer.

3.2 Alumina Adsorption of Arsenic with Microfiltration

Alumina adsorption is a widely recognized technology for the removal of arsenic from water. An innovative approach of using alumina adsorption with microfiltration has been developed by ZENON. The arsenic adsorption microfiltration (AAM) process

aqueous/compound slurries. The pH, oxidation-reduction potential (E_H), arsenic, phosphorus, and calcium concentrations are being monitored as a function of aging time.

After 6 months of aging, all dissolved arsenic concentrations remain below 50 Fg/L. Similar

is presented in Figure 3-2.

Arsenic-contaminated wastewater was pumped to the ZeeWeed Microfiltration process tank. The ZeeWeed Microfilter had a pore size of < 0.2 micrometers (μm) and was installed directly in the process tank. Air was added to the module to continually move the fibers, thereby keeping them clean. The permeate was withdrawn from the process tank by applying a vacuum of 5 to 10 pounds per square inch gauge (psig) on the ZeeWeed membrane.

A suspension of finely divided activated alumina particles was charged to the ZeeWeed Microfiltration tank. The particles have an approximate size of 1.5 μm , and therefore, do not settle readily. It is the small size of the activated alumina that allows the AAM process to be effective because the surface area per particle accessible to the arsenic adsorption is extremely high as opposed to conventional alumina adsorbents that are used in columns. Therefore, the kinetics of adsorption are extremely favorable and rapid.

The first step of arsenic removal involves mixing the arsenic contaminated water with finely divided activated alumina in slurry form in an adsorption reactor. The wastewater was continually

pumped to the well-mixed ZeeWeed process tank and the arsenic was adsorbed onto the activated alumina. Bench-scale testing has demonstrated that the arsenic adsorption kinetics are favorable at a pH of 3 to 4. The ZeeWeed process tank was held at this pH using hydrochloric acid. The ZeeWeed membrane rejects the activated alumina particles, and the permeate (with a very low concentration of arsenic) was discharged. As more and more wastewater was processed, the activated alumina adsorption sites became occupied and the adsorbent was saturated. Regeneration of the absorbent was accomplished by the addition of sodium hydroxide to the process tank until the pH of the activated alumina was approximately 12. The arsenic was then desorbed from the alumina. Formation of a concentrated sodium arsenate brine was generated and recovered during the regeneration cycle. The brine was processed further to convert the arsenic to a physical and chemical form that was most suitable for offsite recycle, reuse, or disposal. Fresh wastewater or process effluent was fed to the process tank at the same rate as the permeate was withdrawn.

Once the alumina regeneration cycle was completed, the flow of the feed to the adsorption/regeneration tank was resumed for another treatment cycle. The concentrated sodium arsenate brine that was recovered during the alumina diafiltration was processed further to convert the arsenic to the physical and chemical form that was most suitable for offsite recycle, reuse, or disposal. The diafiltered solution was then directed to a conventional iron chloride coprecipitation process to recover the arsenic as a sludge. Sampling ports for the alumina adsorption with microfiltration skid are designated (301, 302, 304, 305, 306, FIT, and Filter cake #3) in Figure 3-2. The FIT element in Figure 3-2 denotes the locations of flow indicators. The skid was mobile to facilitate the setup at the different demonstration sites. The alumina adsorption with

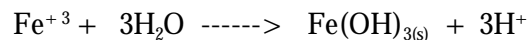
microfiltration technology was demonstrated treating the Mineral Hill Mine 1,300 Portal water at the MSE Testing Facility in Butte, Montana, and the thickener overflow water at the ASARCO East Helena Smelter.

3.3 Ferrihydrite Adsorption of Arsenic

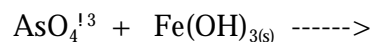
The ferrihydrite process is a commonly used industrial arsenic removal technique. This technology was used as the baseline technology for comparative purposes with the innovative technologies of alumina adsorption with microfiltration and mineral-like precipitation. The ferrihydrite process is illustrated in Figure 3-3.

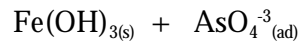
In order for ferrihydrite adsorption to occur, the ferric ion (Fe^{+3}) must be present in the water. Arsenic is most effectively removed from the water when oxidized to the arsenate (As^{+5}) state and the Fe/As mole ratio is greater than 4 at a pH of 4 to 5. Dissolved arsenic is removed from the oxidated water by a lime neutralization process, in the presence of the Fe^{+3} which results in the formation of arsenic-bearing hydrous ferric oxide (ferrihydrite). The ferric ion is not stable in an aqueous environment above pH 7 and will precipitate out as ferric hydroxide (Ref. 9). The chemical reactions for these processes are listed below:

Formation of ferric hydroxide:

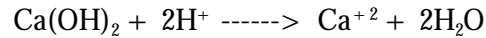


Adsorption and coprecipitation of arsenic(V) with $\text{Fe}(\text{OH})_{3(s)}$:





Acid neutralization with lime (CaO):



The ferrihydrite is separated from the treated water before the process of arsenic removal is complete. The solid-liquid separation is accomplished by a process involving conventional settling/flocculation with pressure filtration.

The ASARCO East Helena Lead Smelter had an existing ferrihydrite system that was used to compare removal efficiencies and process economics for the treatment of arsenic in water to the mineral-like precipitation process and alumina adsorption with microfiltration.

A pilot-scale ferrihydrite system was constructed to treat the Mineral Hill Mine water. Sampling ports are shown in Figure 3-3 for the Mineral Hill Mine demonstration (201, 202, 204, 205, 206, Filtercake #2, pH and FIT). The pH elements indicate the locations of pH probes in tank 201, tank 202, and tank 203. At the ASARCO East Helena Lead Smelter, the sampling ports were the influent, effluent, and sludge sampling locations currently used for the existing ferrihydrite system.

The arsenic-iron sludge from the Mineral Hill Mine Site Demonstration processes was expected to pass toxicity characteristic leaching procedure (TCLP). After this information was verified through testing, the sludge was disposed of at the Butte-Silver Bow Sanitary Landfill. The ASARCO sludge was recycled to its smelter operation.

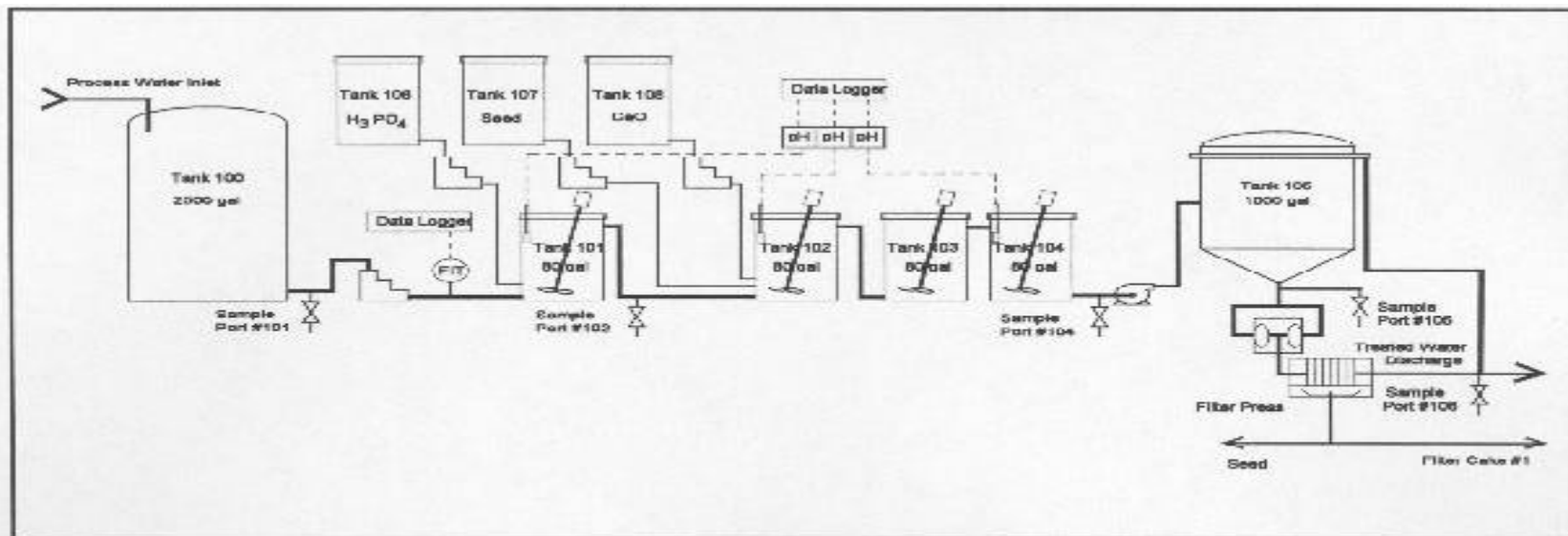


Figure 3-1. Mineral-like precipitation process flow diagram.

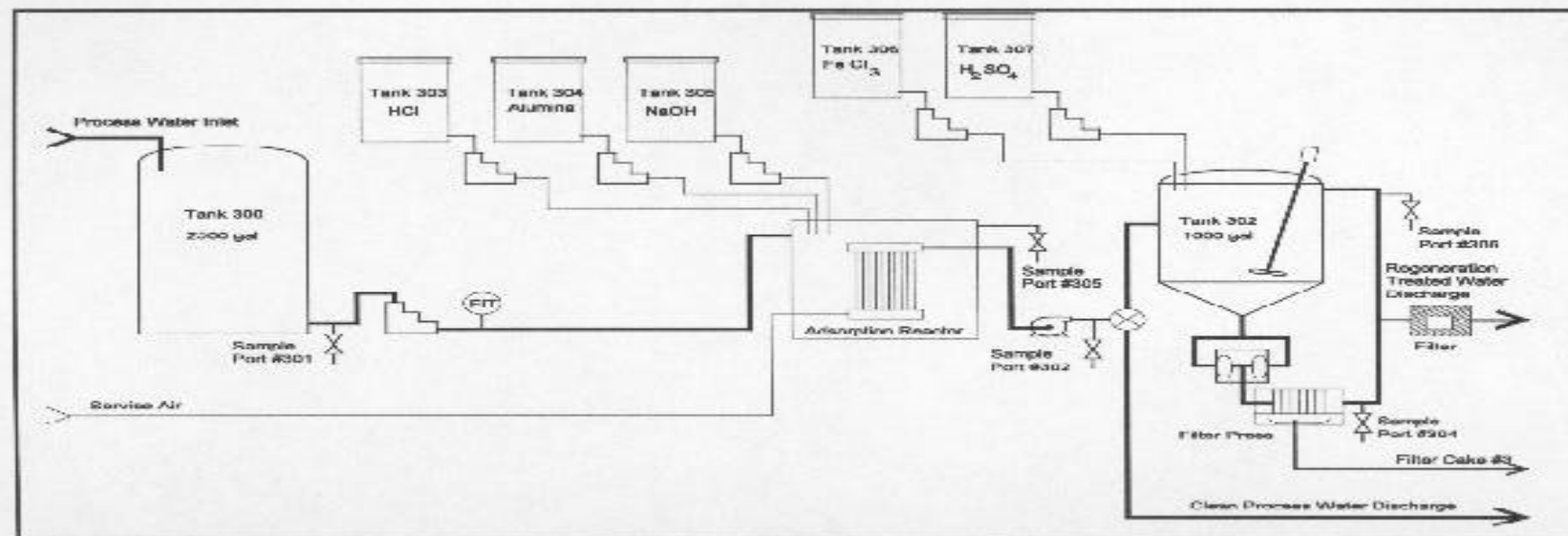


Figure 3-2. Alumina adsorption with microfiltration process flow diagram.

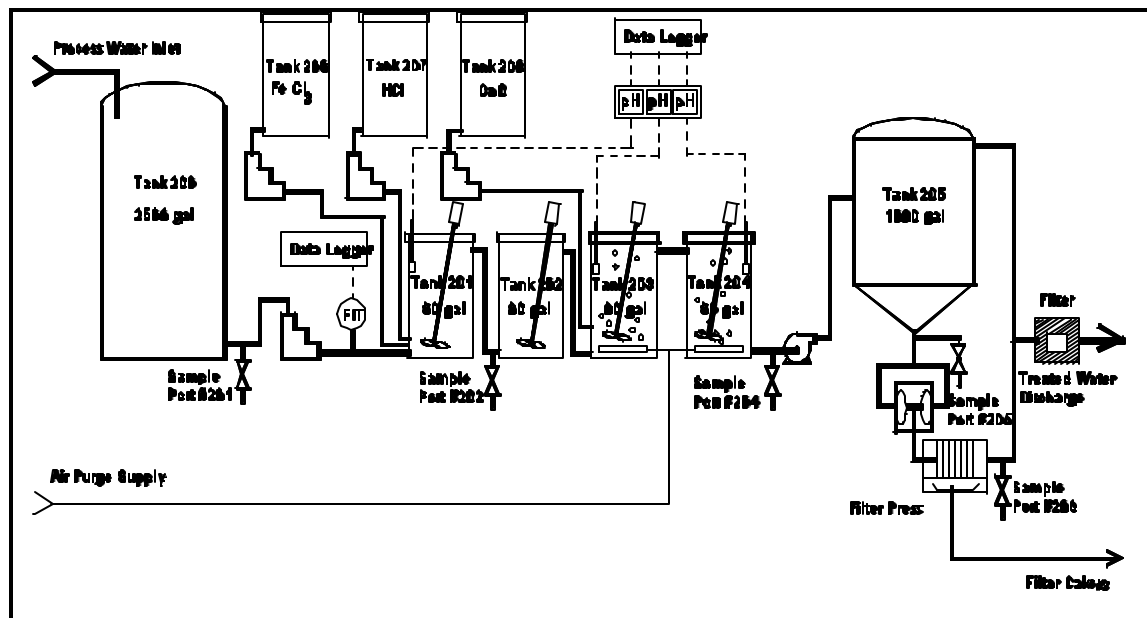


Figure 3-3. Ferrihydrite adsorption process flow diagram.

4. Site Descriptions

The pilot-scale demonstrations were performed at two sites: 1) ASARCO East Helena Lead Smelter in East Helena, Montana, and 2) MSE Testing Facility in Butte, Montana.

All field testing of these processes were conducted by MSE, Montana Tech, and ZENON personnel. Monitoring of pH, E_H , and flow rates were performed at both sites.

All additional inorganic chemical analyses for samples collected at both sites are being conducted at the MSE-HKM Analytical Laboratory, which is located in Butte, Montana. Long-term stability tests are being conducted on the solids produced from the ferrihydrite process and the mineral-like precipitation process at Montana Tech.

4.1 ASARCO East Helena Lead Smelter

The ASARCO East Helena Lead Smelter has been in operation since the late 1800s. The East Helena Smelter is a custom, primary lead smelter that produces lead bullion from a variety of both foreign and domestic concentrates, ores, fluxes, and other nonferrous metal-bearing materials. The East Helena Smelter also produces byproducts such as silver, gold, copper, and sulfuric acid.

The East Helena Smelter is located within the City of East Helena, 3 miles east of Helena, Montana. The demonstration was housed

in the proximity of the Strike Clarified Acid Water Storage Tank Building and the technologies were tested using scrubber blowdown water and/or thickener overflow water from the gas cleaning system prior to entering the acid plant.

Analytical constituents for both the scrubber blowdown and thickener overflow water are presented in Tables 4-1 and 4-2, respectively.

4.2 Mineral Hill Mine

The demonstration was to be held at the Mineral Hill Mine. The Mineral Hill Mine is an underground gold mine owned by TVX Mineral Hill Mining, Inc., and had been in operation intermittently since World War II. Recently, mining operations at the Mineral Hill Mine ceased. The mine is located in Park County, at Jardine, Montana, 5 miles from the community of Gardiner, Montana.

For the duration of the demonstration, Mineral Hill Mine supplied the needed volume of water from the 1,300-foot level portal. Due to some logistical problems, it was decided to haul the Mineral Hill Mine 1,300' Portal water and perform the demonstration at the MSE Testing Facility in Butte, Montana. The untreated water was gravity fed to a tank truck and hauled to MSE. The treated water from the skid was analyzed and discharged to the Butte-Silver Bow sewer system. Analytical results for Mineral Hill Mine water can be seen in Table 4-3.

Table 4-1. Constituents of ASARCO Scrubber Blowdown Water

Constituent	Dissolved Species Concentration, µg/L
As(III)	3,913,000
As(V)	702,000
Cd	412,600
Ca	51,500
Cd	412,600
Cl	2,200,000
Cu	5,000
Fe	29,100
Pb	9,800
Mn	14,300
P	9,000
S	1,117,000
Se	10,400
Si	32,900
Zn	141,600

¹Dissolved concentrations (i.e., sample filtered through a 0.2 micron HDPE filter disk).

Table 4-2. Constituents of ASARCO Thickener Overflow Water

Constituent	Dissolved Species Concentration, µg/L
As(III)	4,060
As(Total)	5,810
Ca	732,400
Cd	20
Cu	10
Fe	30

Table 4-2. Constituents of ASARCO Thickener Overflow Water

Constituent	Dissolved Species Concentration, µg/L
Pb	< 20
Mn	20
P	24,600
S	812,000
Se	1,410
Zn	< 9

¹Dissolved concentrations (i.e., sample filtered through a 0.2 micron HPDE filter disk except for arsenic). The arsenic speciation was determined on an unfiltered sample.

Table 4-3. Constituents of Mineral Hill Mine 1,300' Portal Water

Constituent	Dissolved Species Concentration, µg/L
As(V)	366
As(Total)	362 (range was 366-670)
Ca	124,600
Cd	10
Cu	10
Fe	< 24
Pb	< 20
P	< 30
SO ₄ ⁻²	181,000
Zn	< 10

¹Dissolved concentration (i.e., sample filtered through a 0.2 micron HPDE filter disk).

5. Quality Assurance

MSE developed a QAPP (Ref. 3) to control the experimental test work design for the Arsenic Removal Project. The Test Plan (Ref. 9) was developed to implement the QAPP and the associated scope of work for the demonstrations and management of each project. The QAPP was written to followed EPA Category II procedures. Sampling

Procedures, and Analytical Procedures and Calibration along with sample port/location descriptions, sample matrix, noncritical and critical measurements and frequency for each process demonstration are attached in Appendix A. For further information on the experimental design, refer to the QAPP and Work Plan references (Refs. 3 and 9).

6. Field and Laboratory Data Validation Report

In August of 1997, sampling officially began for the MWTP Activity III, Project 9—Arsenic Removal Demonstration. Sampling, analyzing, and calibration procedures are presented in Appendix A.

6.1 Project Audits

An audit of a specific portion of each technology demonstration was performed throughout the project:

- C Field Systems Audit at ASARCO for the Alumina Adsorption Process;
- C Metals Analysis Review at Montana Tech for the Mineral-Like Precipitation Process; and
- C Sample Collection/Decontamination Procedures Review at the MSE Testing Facility for the Ferrihydrite Adsorption Process.

6.1.1 Field Systems Audit at ASARCO

A field systems audit was performed on August 14, 1997, at the Alumina Adsorption process demonstration at the ASARCO Lead Smelting Plant. The Alumina Adsorption process was demonstrated by ZENON Environmental, Inc. The system audit included a review of the following items:

- personnel, facilities, and equipment;
- documentation [chain-of-custody (COC), logbooks];
- calibration of equipment; and
- sampling procedures.

No concerns were identified during the audit.

6.1.1.1 Personnel, Facilities, and Equipment

Personnel present during the audit included: Jay McCloskey, Technical Project Manager; Dave Reisenauer, Operator; Glenn Vicevic, ZENON, Project Manager; and Greg McGinn, ZENON, Operator.

The demonstration was held at the ASARCO lead smelting plant, located in East Helena, Montana. Equipment for the demonstration was housed in the acid plant at the smelter. Analysis and preparation of the samples (filtering, preserving) was performed in the plant on a table specifically designed for that purpose. Project personnel were knowledgeable about the demonstration and their duties and responsibilities at the demonstration site.

All ZENON equipment was checked prior to shipment with National Institute of Standards and Technology (NIST) secondary standards on a scheduled basis. All calibration information was available on the equipment checkout sheet provided by ZENON. ZENON is ISO and its personnel were familiar with quality assurance (QA) procedures in general.

6.1.1.2 Documentation

Chain-of-custody procedures were reviewed at the demonstration site and all COC procedures were being followed. The project logbooks were also reviewed. The sampling logbook was very thorough and included spaces where specific information was required. Sampling personnel were familiar with the logbook format and COC procedures.

6.1.1.3 Calibration of Equipment

Field equipment was used to collect pH and flow rate. This information was recorded from digital readouts on the demonstration skid. The pH was also verified by collecting a

sample and measuring the pH with a pH meter. Standard operating procedures (SOP) were available at the demonstration site to calibrate/operate the pH meter and the ZENON alumina adsorption skid. Sampling personnel were familiar with the SOPs and requirements for routine calibration of the pH meter.

6.1.1.4 Sampling Procedures

A review of sampling activities was also performed during the systems audit. Operations personnel from MSE and ZENON were trained by MSE-HKM Laboratory personnel in proper sampling procedures. ZENON personnel were familiar with sampling procedures because similar procedures were used during the ZENON demonstration for the Resource Recovery Project at the MSE Testing Facility. All sample collection and equipment decontamination procedures were followed by sampling personnel.

Samples were stored in a refrigerator at 4 °C at the demonstration site prior to shipment to the laboratory. The most critical holding times were for arsenic and iron speciation. Samples were shipped via ground transportation in sealed coolers filled with ice by project personnel. The drive from the ASARCO lead smelting plant to the laboratory took approximately 60 minutes. For the mineral-like precipitation process demonstration, an audit of arsenic analysis was performed at Montana Tech.

6.1.2 Metals Analysis Review at Montana Tech

In addition to the systems audit in the field, an audit of Inductively Coupled Plasma (ICP) with Hydride Generation for arsenic analysis in the Metallurgy Department at Montana Tech was performed on the evening of August 14, 1997. The analyst was Michelle Gale, a graduate student from Montana Tech assisting Dr. Larry Twidwell on the mineral-like precipitation demonstration. For the entire duration of the project, ICP analysis had been performed by Montana Tech to assess how the process is operating and allow for process changes if warranted. The

purpose of the metals analysis at Montana Tech was to determine the arsenic concentration throughout the process with shorter turnaround times than the MSE-HKM Laboratory. Arsenic was the only analysis performed.

A Varian Liberty 110 ICP was used for the analysis. The ICP was calibrated with three standards and a blank. Quality control (QC) checks included continuing calibration verification (CCV), continuing calibration blank (CCB), preparation blank, laboratory control sample (LCS), and duplicates. During the first run, the ICP analysis was out of control limits for the CCV. A sampler tube was changed, the ICP was recalibrated, and the analysis proceeded until all of the samples had been analyzed. The analysis generated some interesting results that identified a possible problem with decontamination of tanks and hoses following the ASARCO demonstration of the mineral-like precipitation process. The influent to the system has a concentration of approximately 450 ppb, while the initial tanks in the system had concentrations of approximately 600 ppb. These results indicated that arsenic was being added to the system rather than being removed. When the effluent sample was analyzed, the result was only 8 ppb, which easily met the objective. To determine the source of the arsenic contamination, the decontamination procedures following the ASARCO demonstration were most likely not rigorous enough. While the tanks were acid washed, it was discovered that the hoses may not have been flushed thoroughly, which could account for the elevation of arsenic in the early stages of the process. In any case, the mineral-like precipitation process was able to remove the additional arsenic. In the future, the wastewater with the lowest concentration (Mineral Hill Mine Water) should be demonstrated first and then the wastewater with the higher concentration (ASARCO) could be demonstrated.

6.1.3 Sample Collection/ Decontamination Procedures Review at the MSE Testing Facility

For the ferrihydrite adsorption of arsenic portion of the demonstration, sample collection procedures were witnessed on 09/05/97, near the end of the demonstration. The purpose of the audit was to oversee sample collection and equipment decontamination procedures performed by project personnel at the MSE Testing Facility. Rich Henningsen, a process engineer, performed the sampling. First, a sample for iron and arsenic was collected from the ferrihydrite adsorption process, then filtered using pressure filtration, preserved with nitric acid, capped, labeled, and recorded in the project logbook. The filtering apparatus was then decontaminated with a 1:1 nitric acid and thoroughly rinsed with deionized (DI) water. To determine whether decontamination procedures were effective, a field external decontamination blank was collected. The field external decontamination blank results give an indication of contamination introduced through sampling procedures, field equipment (filter and filtering apparatus), preservation, and carryover after decontamination, as well as contamination introduced in the laboratory. The MSE-HKM Laboratory reported the results of this sample, and the results showed no contamination at < 40 ppb by inductively coupled plasma atomic emission spectroscopy (ICP) and < 1 ppb by atomic absorption (AA) analysis. The results of this blank indicate that the decontamination procedures for sampling equipment used during the project were rigorous enough. Results of other field QC samples are discussed in Section 6.2.4 of this report.

6.2 Data Evaluation

In addition to the systems audits performed during the project, all field and laboratory data has been evaluated to determine the usability of the data. The final project samples were collected on September 8, 1997.

To determine the effectiveness of the arsenic removal processes being demonstrated, several sampling points were designated for

each process and a variety of analyses were assigned to each point. The analyses to be performed were specified in the project-specific QAPP (Ref. 3), and each analysis was classified as critical or noncritical. A critical analysis is one that must be performed in order to achieve project objectives. A noncritical analysis is one that is performed to provide additional information about the process being tested.

Critical analyses for this project are summarized below.

- Dissolved arsenic; and
- TCLP for arsenic.

Noncritical analyses for this project are listed below:

- pH;
- E_H ;
- total flow;
- temperature;
- flow rate;
- arsenic speciation;
- iron speciation;
- dissolved metals (Al, As, Cd, Cu, Fe, Pb, P, Zn, Ca);
- total recoverable metals (Al, As, Cd, Cu, Fe, Pb, P, Zn, Ca);
- total metals (As, Ba, Cr, Cd, Cu, Fe, Pb, P, Ag, Zn, Ca);
- percent solids; and
- TCLP (Ba, Cd, Cr, Pb, Hg, Se, Ag).

The QC objectives for each critical analysis were outlined in the QAPP and were compatible with project objectives and the methods of determination being used. Additional information on critical and noncritical analysis is available in Appendix A. The QC objectives are method detection limits (MDLs), accuracy, precision, and completeness. Control limits for each of these

objectives were established for each critical analysis. For noncritical analyses, QC objectives were determined using standard guidelines that exist or applying reasonable control limits in order to determine the usability of the data.

6.3 Validation Procedures

Data that was generated for all critical and noncritical analyses was validated. The purpose of data validation is to determine the usability of all data that was generated during the project. Data validation consists of two separate evaluations: 1) an analytical evaluation, and 2) a program evaluation.

6.3.1 Analytical Evaluation

An analytical evaluation is performed to determine the following:

- C All analyses were performed within specified holding times;
- C Calibration procedures were correctly followed by field and laboratory personnel;
- C Laboratory analytical blanks contain no significant contamination;
- C All necessary independent check standards were prepared and analyzed at the proper frequency and all remained within control limits;
- C Duplicate sample analysis was performed at the proper frequency, and all Relative Percent Differences (RPDs) were within specified control limits;
- C Matrix spike sample analysis was performed at the proper frequency and all spike recoveries (%R) were within specified control limits; and

- C Data in the report submitted by the laboratory to project personnel can be verified from the raw data generated by the laboratory.

Measurements that fall outside of the control limits specified in the QAPP, or for other reasons are judged to be outlier, were flagged appropriately to indicate that the data is judged to be estimated or unusable. All QC outliers for all sampling events are summarized in Table 6-2. In addition to the analytical evaluation, a program evaluation was performed.

6.3.2 Program Evaluation

Program evaluations include an examination of data generated during the project to determine the following:

- C All information contained in COCs is consistent with the sample information in field logs, laboratory raw data, and laboratory reports;
- C All samples, including field QC samples, were collected, sent to the appropriate laboratory for analysis, and analyzed and reported by the laboratory for the appropriate analyses;
- C All field blanks contain no significant contamination; and
- C All field duplicate samples demonstrate precision of field as well as laboratory procedures by remaining within control limits established for RPD.

Program data that was inconsistent or incomplete and did not meet the QC objectives outlined in the QAPP were viewed as program outliers and were flagged appropriately to indicate the usability of the data. Both the analytical and program evaluations consisted of

evaluating the data generated in the field as well as in the laboratory.

6.4 Analytical Evaluation

The analytical evaluation of field and laboratory data was completed in November of 1997.

6.4.1 Field Logbook Evaluation

Field data validation began with an examination of the field log books that were created for this project. Sampling logbooks were created for each process test. General site logbooks were also created for the demonstration by MSE personnel and Australian Nuclear Science and Technology Organization (ANSTO) personnel. The field logbook typically contains all of the information that is available regarding the following:

- information about fieldwork performed; and
- sample collection activities,

6.4.1.1 Information About Fieldwork Performed

The general logbooks contained daily logs of fieldwork performed and process measurements taken. Feed and tank changes were noted in the general logbook.

6.4.1.2 Sample Collection Activities

Sampling logbooks contained all of the appropriate information for sample collection and field measurements that were taken. Sampling conditions and information such as weather conditions, date of sampling, time of sampling, and details of fieldwork performed should be specified in the field logbook for each sampling event. Sampling information was complete and accurate for all sampling events. While a specific space was not provided for additional comments or information, sampling personnel made notes in the margins when necessary. The sampling logbook format facilitated review by specifying a space for each

measurement to be recorded in; therefore, missing information was easy to locate. All of the preservatives required for each analysis were clearly listed in the sampling logbooks. The logbooks for the alumina adsorption process contained the wrong sample preservatives for sulfate and total suspended solids (TSS) analysis; however, this problem was discovered and corrected in the field although it could have been a serious problem that affected the entire test series for the alumina adsorption process. Table 17 in the QAPP summarized the analyses and the proper preservatives for all of the analyses and similar tables in future QAPPs should be consulted when creating logbooks. In addition, any new personnel used for sampling activities should be made aware of the QAPP and the procedures outlined in the QAPP to avoid this mistake in the future.

6.4.2 Field Data Validation

Field data validation was performed to determine the usability of the data that was generated during field activities. The usability was determined by verifying that correct calibration procedures of field instruments were followed. Standard operating procedures for calibration of field instruments were available at the demonstration site. All of the field measurements were classified as noncritical. The following measurements were performed in the field:

- E_H ;
- pH;
- temperature;
- flow rate; and
- total flow.

Table 6-1 summarizes the measurements that were not recorded in the logbook for the various tests. There was no justification provided in the logbook as to why the data was not collected. The

reason(s) for not recording measurements should be provided in the logbook.

6.4.2.2 E_H

An Orion E_H meter with a silver/silver chloride reference electrode was used to determine the E_H of samples at the demonstration site. The electrode was calibrated using Zoebell's solution of known E_H . All E_H data are considered usable. The calibration was not documented in the project logbooks; however, during the demonstration audit, project personnel indicated the E_H meter was calibrated each day measurements were taken. All equipment calibrations should be documented in the project logbooks. Refer to Table 6-1 for the dates and times E_H was not recorded in the logbook for each test.

6.4.2.3 pH

The pH meter was calibrated using two known buffer solutions that would bracket the measured pH. Calibration of the pH meter was performed each day pH measurements were taken. The pH data were also recorded from pH meters installed in the process skids, if available. All pH data are considered usable. Refer to Table 6-1 for the dates and times pH was not recorded in the logbook for each test.

6.4.2.4 Temperature

Temperatures of the process inlets and outlets were measured using the thermistor in the pH meter or mercury thermometers. The thermistor and the mercury thermometers were calibrated by the Instrumentation and Control Department on a regular basis according to the manufacturer's instructions. All temperatures were recorded in the project logbooks when measurements were taken, and all temperature data is considered usable. Refer to Table 6-1 for the dates and times temperature measurements were not recorded in the logbook for each test.

6.4.2.5 Flow Rate and Total Flow

Flow rates and total flow were determined using flow meters or flow totalizers installed within each process skid. Project personnel recorded the flow rate or total flow from a digital readout. Refer to Table 6-1 for the dates and times that flow measurements were not recorded in the project logbooks.

6.4.3 Laboratory Data Validation

Laboratory data validation was performed to determine the usability of the data that was generated by the laboratory for the project. The following analyses were performed in the MSE-HKM Laboratory:

- arsenic speciation (noncritical);
- iron speciation (noncritical);
- dissolved metals (Al, As, Cd, Cu, Fe, Pb, P, Zn, Ca) (critical and noncritical);
- TCLP (critical);
- total recoverable metals (Al, As, Cd, Cu, Fe, Pb, P, Zn, Ca, Na) (noncritical);
- total metals (As, Ba, Cd, Cr, Cu, Fe, Pb, P, Zn, Ca, Na) (noncritical); and
- percent solids (noncritical).

Laboratory data validation was performed using *USEPA Contract Laboratory Program National Functional Guidelines for Inorganics Data Review* (Ref. 10) as a guide (where applicable) to each individual analysis. For critical analyses, the QC criteria outlined in the QAPP were also used to identify outlier data and determine the usability of the data for each analysis. When data validation was initiated, the MSE-HKM Laboratory was not sending sufficient information to perform a complete and thorough data validation. Due to the large volume of data generated for the project, the data validation was performed at the laboratory or by

electronic copy rather than requiring the laboratory to submit copies of all data generated for the project.

6.4.3.1 Arsenic Speciation

Arsenic speciation analysis was performed at the MSE-HKM Laboratory. The concentration of As^{+3} and As^{+5} in project samples was determined using furnace AA, following the speciation of the arsenic using the Ion Exchange Ficklin Method. The procedure involves passing 5 milliliters (mL) of the filtered, acidified sample through an ion exchange column packed with Donwex 1 x 8 anion-exchange resin in 100-200 mesh size. The As^{+5} adheres to the acetate form of the ion exchange resin while the As^{+3} passes through the column. To ensure the recovery of all of the As^{+3} , the column is eluted with three separate 5-mL portion of DI water. The original sample and each elution are collected in separate vials numbered 1 through 4. These vials contain the As^{+3} from the original sample. The column is then eluted with three separate 5 mL portions of 0.12 million (M) hydrochloric acid (HCl). The pH change and the subsequent ion exchange causes the As^{+5} to pass through the column and the three vials containing the last three elutions contain the As^{+5} . All of the speciation vials as well as an unspicated total dissolved arsenic sample will be analyzed by furnace AA to determine the concentrations of As^{+3} , As^{+5} , and total dissolved As. Samples requiring qualification for arsenic speciation analysis are summarized in Table 6-2.

6.4.3.2 Iron Speciation

Iron speciation was performed at the MSE-HKM Laboratory. The concentration of ferrous iron will be determined using a modified colorimetric Standard Method 3500-Fe D from *Standard Methods for the Examination of Water and Wastewater*, which uses phenanthroline as the color developer. Total iron is measured similarly after reducing the iron in the sample to the ferrous state by boiling using acid and hydroxylamine and treating with 1,10-phenanthroline at a pH of 3.2 to 3.3. The concentration of the

ferric iron was then calculated by subtracting the concentration of ferrous iron from the concentration of total iron. The spectrophotometer was calibrated with a blank and at least three standards. All iron speciation data is considered usable and required no qualification.

6.4.3.3 Aqueous Metals Analysis by ICP

Dissolved and total recoverable metals concentrations and concentrations in TCLP extracts were determined using SW-846 Method 6010A on a Varian Liberty 110 ICP. The samples were prepared according to SW-846 Method 3005A. The ICP was calibrated according to procedures outlined in SW-846 Method 6010A and the equipment manufacturer's instructions. Calibration consisted of the following procedures and items:

- mixed calibration standards;
- calibration blanks and reagent blanks;
- independent check standards;
- interference check solutions; and
- QC samples.

Refer to Table 6-2 for samples requiring qualification for ICP analysis.

6.4.3.4 Aqueous Metals Analysis by Atomic Adsorption

Because the ICP was not sensitive enough to detect arsenic concentrations below 40 ppb, all samples with concentrations below 100 ppb by ICP were reanalyzed by AA to more accurately determine the concentration of arsenic at lower levels. One batch of AA analyses required qualification due to an analytical spike that was out of control. Because the spike recovery was low (76.5%), there may be a slight negative bias in the arsenic concentrations for these samples. Refer to Table 6-2 for the data requiring qualification for AA analysis.

6.4.3.5 Toxicity Characteristic Leaching Procedure

Solid materials were subjected to the TCLP procedure outlined in SW-846 Method 1311 at the MSE-HKM Laboratory. The resulting extraction fluids from the TCLP were digested according to procedures outlined in SW-846 Method 3005A for total recoverable metals. In addition to the reagents listed in the method, 20 mL of 30% hydrogen peroxide (H₂O₂) was added to the samples prior to digestion to help degrade the acetic acid. Digested samples were analyzed by ICP with the exception of mercury. Mercury was analyzed by cold vapor AA according to SW-846 Method 7470. All TCLP data is considered usable, and none of the TCLP data was qualified.

6.4.3.6 Solid Metals Analysis/Percent Solids

Solid samples were characterized for total metals by ICP according to SW-846 Method 6010A at the MSE-HKM Laboratory. Samples were digested according to SW-846 Method 3050A. The percent solids of each sample was also determined using the method outlined in Exhibit D, Part F of the *Contract Laboratory Program Statement of Work*, Document Number IL03.0. The method involves weighing a wet portion of the solid material, drying the sample in an oven to constant weight, then reweighing the sample to determine the moisture lost during drying. The percent solids data was used to report the total metals on a dry weight basis. All percent solids data is considered usable and required no qualification.

6.5 Program Evaluation

The program evaluation focused on the following areas:

- COC procedures;
- sampling and data completeness;
- field blanks; and
- field duplicates.

6.5.1 Chain-of-Custody Procedures

All information provided in the COC forms for this project was complete and accurate; however, on several occasions changes were made on the COC forms and were not initialed and dated. All changes made to COC or project logbooks should be made by striking out the mistake with a single line and initialing and dating the change.

6.5.2 Sampling and Data Completeness

All samples that were supposed to be collected were collected. During several tests extra samples were also collected and fully documented in the project logbooks. All collected samples were analyzed for the requested analyses on the COC forms.

6.5.3 Field QC Samples

All field QC samples were collected at the proper frequency for tests specified in the QAPP. All samples requiring qualification due to field QC samples are summarized in Table 6-2.

6.5.3.1 Field Blanks

None of the field blanks collected for the project showed significant contamination.

6.5.3.2 Field Duplicates

Field duplicates showed very good agreement with the original samples, with the following exception:

Alumina Adsorption Test at ASARCO

C Dissolved arsenic duplicate sampled on 08/14/97 was out of control for arsenic analysis by AA.

See Table 6-2 for a summary of qualified data due to this out of control field QC sample.

6.6 Summary

While the majority of the findings of the analytical and program evaluations are minor and can be easily addressed or have already been addressed, several lessons can be learned so that mistakes will not be repeated during future projects. The following recommendations are suggested in order to improve future project and program QA/QC.

6.6.1 Laboratory QA/QC

QA/QC summaries and raw data were available for review at the MSE-HKM Laboratory upon

request; however, prior to future projects, project personnel should inform any laboratory performing analyses about QA/QC reporting needs (QA/QC summaries and raw data should be attached to the report).

6.6.2 Field QA/QC

Field sample identification numbers included the sample port number so that influent and effluent samples could be distinguished from one another on the laboratory report. When questionable data was reported, the reviewer had to have the field log data sheets to determine if the sample was an influent or effluent. More descriptive sample identification numbers would make the data review process much easier.

There was a great volume of data generated during this project, and while some of the data is considered estimated for various reasons, the fact that all of the data is usable underlines the fact that quality data was generated for MWTP Activity III, Project 9.

Table 6-1. Summary of Field Measurements Not Recorded in Logbook

Date	Time	Measurements not recorded
<u>Mineral-Like Precipitation at ASARCO</u>		
	21:35, 00:30, 1:29	Flow rate
<u>Alumina Adsorption with Mineral Hill Mine Water</u>		
35666.0	22:00 (time was recorded as 10:00; however, military time should be used so each sample time is unique to avoid confusion)	Flow rate
08/26/97	10:00	pH
08/26/97	16:00	Total Flow
<u>Iron Co-Precipitation with Mineral Hill Water</u>		
35681.0	9:20, 13:20	Temperature
09/10/97	07:00	Flow rate, Temperature, pH, E _H
Extra Samples after scheduled test completed	Similar data should be collected on extra samples for comparability	pH

Table 6-2. Summary of Qualified Data for MWTP Activity III, Project 9

Date¹	Sample ID	Analysis	QC Criteria	Control Limit	Result	Flag²	Comment
	ASARCOLL# 1	As Speciation	Total Recovery	80%-120% Recovery of Arsenic Species	125.9% Recovery	J	The recovery of arsenic species was outside specified control limits.
	ASARCOLL# 2	As Speciation	Total Recovery	80%-120% Recovery of Arsenic Species	123.2% Recovery	J	The recovery of arsenic species was outside specified control limits
	Feed 1A	Total Recoverable Cu	Duplicate	#20% RPD	23% RPD	J	Duplicate results differed significantly enough to flag associated samples "J", as estimated.
		Fe			22.6% RPD	J	
		Pb			48.4% RPD	J	
		Al			43% RPD	J	
		Mg			21.8 % RPD	J	
		P			47.1% RPD	J	
08/14/97	PLA2-105 PLA2-106 PLA2-108 PLA2-110 PLA2-111 PLA2-113 PLA2-115 PLA2-118 PLA2-126	Diss As by AA	Field Duplicate	Reviewer Discretion (Laboratory Duplicate Control Limit is #20% RPD)	63.8% RPD	J	Field duplicate results differed significantly enough to flag associated samples "J", as estimated.
08/18/97	ALA-162	Diss As Al	Duplicate	#20% RPD	136.2% RPD 56.6% RPD	J J	Duplicate results differed significantly enough to flag associated samples "J", as estimated.
08/17/97 08/17/97	MLM-344 MLM-346	Diss P	CCV	89-111% Recovery	112.3% Recovery	J	Samples over the IDL are qualified "J" as estimated due to out of control CCV.
08/17/97 08/17/97 08/17/97	ALA-132A ALA-133A ALA-132B	Diss Al	CCV	89-111% Recovery	112.3% Recovery	J	Samples over the IDL are qualified "J" as estimated due to out of control CCV.

¹ Date that the samples were collected.

² Data Qualifier Definitions:

U—The material was analyzed for, but was not detected above the level of the associated value (quantitation or detection limit).

J—The sample results are estimated.

R—The sample results are unusable.

UJ—The material was analyzed for, but was not detected, and the associated value is estimated.

Table 6-2. Summary of Qualified Data for MWTP Activity III, Project 9 (cont.)

Date ¹	Sample ID	Analysis	QC Criteria	Control Limit	Result	Flag ²	Comment
08/04/97	MLA-214	Diss As by AA	Analytical Spike	85%-115% Recovery	76.5%Recovery	J	Analytical spike results were out of control and the sample concentration was less than 50% of the spike concentration.
08/04/97	MLA-216						
08/04/97	MLA-216A						
08/04/97	MLA-216B						
08/03/97	MLA-202						
08/03/97	MLA-204						
08/04/97	MLA-108						
07/24/97	MLA-210A						
07/24/97	MHA-102						
07/24/97	MHA-104A						
07/25/97	MHA-119A						
07/25/97	MHA-120						
07/24/97	MHA-108						
07/24/97	MHA-108A						
07/25/97	MHA-124						
07/25/97	MHA-125						
07/25/97	MHA-126						

¹ Date that the samples were collected.

² Data Qualifier Definitions:

U-The material was analyzed for, but was not detected above the level of the associated value (quantitation or detection limit).

J-The sample results are estimated.

R-The sample results are unusable.

UJ-The material was analyzed for, but was not detected, and the associated value is estimated.

7. Demonstration Results

7.1 Mineral-Like Precipitation Results

7.1.1 ASARCO Scrubber Blowdown Water Analytical Results

The removal of arsenic from ASARCO scrubber blowdown water by the mineral-like precipitation technology using a phosphorous to arsenic mole ratio of 7 was very effective. The effluent water from the settler (after 24-hours continuous operation) contained < 10 ppb arsenic (the goal was to remove the arsenic to below 50 ppb). The experimental results are summarized in Table 7-1, while the complete experimental results are presented in Appendix B. The influent composition and the final effluent water from the treatment system are presented in Table 7-2. The solution pH, E_H , and temperature data are summarized in Table 7-3.

The removal of arsenic from scrubber blowdown water is dependent on the addition of the proper amount of lime (see Figure 7-1). The solubility of arsenic as APHAP is depicted in this figure. The data used to generate the figure is based on the standard free energy of formation of APHAP as determined by Twidwell, et al (Ref. 7). Note that approximately 40 g/L lime should be required for effective removal of arsenic for an influent arsenic concentration of 3.0 g/L. The demonstration test was conducted using 56 g/L lime. Figure 7-2 shows that approximately 50 g/L lime was required to raise the pH of the scrubber blowdown water to 11 and above.

7.1.2 Solid Characterization

Solids were collected from the settler at the end of each test run. The percent solids in the settler bottoms were 21.9% (for the 24-hour test) and 20.2% (for the 3-hour test). Aliquot samples were split from the slurries and were

used for settling rate studies. Each settler bottom slurry was filtered. The filtrates were saved and used in the long-term stability tests (see Section 7.1.4) and will be used to replace the solution that evaporates with time from the long-term aging samples. The solids were saved for characterization studies that included elemental characterization, x-ray diffraction, scanning electron microscopy (and energy dispersive spectroscopy), and long-term stability during storage.

7.1.3 Toxicity Characteristic Leaching Procedure

The TCLP was performed on the composite solids produced at the end of each treatment series. Total metals concentration and TCLP results are presented in Table 7-4 for the 24-hour, P/As mole ratio = ~ 5.5 test and Table 7-5 for the 3-hour, phosphorus (P)/As mole ratio = ~ 11.9 test. Note that product solids from the 24-hour test passed the TCLP test but the solids from the short (higher phosphorus) time (3-hour) test did not. Therefore, the first test solids are considered to be nonhazardous with respect to handling and land disposal; however, the second test solids are considered hazardous. The reason that the second test solids did not pass the TCLP is presently not known, although the very short duration of the test (i.e., only 3 hours) may be the reason. Even though the second test solids did not pass the TCLP test, the solids are being subjected to long-term leach testing.

7.1.4 Long-Term Stability

The need for long-term stability testing was previously presented in Section 3.1 [i.e., the solids that are produced by other technologies (lime precipitation and ferrihydrite adsorption) may not be stable for long-term outdoor storage]. The mineral-like precipitation

technology solves the storage problem because the product is thermodynamically stable against conversion to calcium carbonate by carbon dioxide in atmospheric air.

To validate that the mineral-like product was indeed stable, long-term stability tests were initiated and will be continued for 2 years. Briefly, the aging test procedure consists of the following steps.

- C One-hundred grams of filter press solids (percent moisture determined) were placed in 1-liter of effluent solution in high-density polyethylene (HDPE) bottles. Triplicate test slurries were prepared.
- C The slurries were shaken for 24 hours, pH and E_H were determined, and solution samples were extracted, preserved, and submitted to MSE-HKM for analytical characterization. These samples are considered time zero for the aging demonstration.
- C Each sample bottle was then set so that air could be sparged into the slurry at 10 mL/min. Presently, solution pH, E_H , and temperature are being monitored monthly.
- C The solubility of the solids will be determined after 1 and 2 years of exposure.

The time zero analytical results for the ASARCO scrubber blowdown water are presented in Table 7-6.

7.1.5 X-ray Diffraction

The solids were subjected to x-ray diffraction. The x-ray diffraction patterns are presented in Figure 7-3. The patterns for the solids produced from both the 20-hour and 3-hour tests appear to be very similar. The pattern for

the 20-hour test is presented in Figure 7-3. Note that a semicrystalline product is represented and that there is a cluster of peaks in the 2-theta range 30-36°. This pattern is similar (but the crystallinity is not yet well developed) to the apatite and apatite-like minerals. The APHAP compounds have the same crystal structure as hydroxyapatite (HAP) and arsenatehydroxyapatite (AHAP) (i.e., Johnbaomite). This is illustrated in Figure 7-4. Note that the solid solution APHAP compound major peaks lie between the HAP (no As present) and AHAP (no P present) major peaks. Note also that the pattern for the ASARCO solid (which contains approximately 2.1%–2.7% arsenic) as seen in Figure 7-3, when superimposed on the pattern for APHAP (which contains 2.9% arsenic) shows excellent similarity (see Figure 7-5).

7.2 ASARCO Thickener Overflow Analytical Results

The removal of arsenic from ASARCO thickener overflow water by the mineral-like precipitation technology was very effective [e.g., the effluent water from the settler (after 8-hours continuous operation) was less than 15 ppb arsenic (the goal was to remove the arsenic to below 50 ppb)]. The experimental results are summarized in Table 7-7. The input water composition and the final effluent water composition from the treatment system is presented in Table 7-8. The solution pH, E_H , and temperature data are summarized in Table 7-9. The arsenic removal was enhanced by increasing the P/As mole ratio. The removal of arsenic was very rapid at the higher P/As ratio (i.e., the arsenic content was less than 10 ppb in less than 15 minutes). This effect is demonstrated by the data presented in Table 7-9.

The data for two separate tests are summarized in Table 7-7 (i.e., the first test was conducted for 16 hours using a nominal

P/As mole ratio of 10; the second test was conducted for 20 hours using a nominal P/As mole ratio of 100). The reason for increasing the P/As mole ratio to 100 is described below.

Samples were taken from Tank 101 (the phosphate addition tank) early in the test period. These samples were taken to Montana Tech for quick analyses. The results showed there was essentially no phosphorus available in the solution phase in Tank 101 (i.e., samples filtered through 0.2 μm filter disks showed only a few parts per billion phosphorus present but samples not filtered showed the proper phosphorus content). The phosphorus was being adsorbed onto an organic phase (probably from the filteraid used in the thickener). Therefore, the first test was terminated at 16 hours. However, as noted in Table 7-7, the loss of phosphorus from the aqueous solution turned out to be a nonissue [i.e., excellent arsenic removal was achieved (after approximately 8 hours of operation) at the lower P/As ratio].

The removal of arsenic from ASARCO water treatment thickener overflow water requires only minor lime addition. It would appear that the thickener water (already at a pH of ~ 11 and a calcium content of ~ 730 mg/L) should precipitate the APHAP compound without addition of more lime. However, as the data from sampling port 102, (the water exiting the inlet reactor plus phosphate addition tank) shows, arsenic was not precipitated (see Figure 3-1). The reason for this result is because much of the phosphate was adsorbed onto the entrained flocculant. However, by adding more lime to the system, arsenic was stripped from the solution and flocculant. The demonstration test was conducted by adding sufficient lime to bring the lime content in the water to 1 g/L. This addition, illustrated in Figure 7-6, raised the solution pH to approximately 12. It is likely that effective

arsenic removal could have been achieved with a much smaller lime addition (i.e., note that in Figure 7-6, the solution pH would still be above 10, even at a lime addition rate of 0.25 g/L). The unknown at this point is whether minor lime addition rates would strip the phosphate from the flocculate.

7.2.1 Toxicity Characteristic Leaching Procedure

The TCLP was performed on the composite solids produced at the end of each treatment process. Total metals concentration and TCLP results are presented in Table 7-10 for the 20-hour test, P/As mole ratio= 100. Note that product solids from the treatment sequence passed the TCLP test. Therefore, these solids are considered to be nonhazardous with respect to handling and land disposal.

7.2.2 Long-Term Stability

The need for long-term stability testing was presented previously in Sections 3.1 and 7.1.4, [i.e., the solids produced by other technologies (lime precipitation and ferrihydrite adsorption) may not be stable for long-term outdoor storage]. The mineral-like precipitation technology solves the storage problem because the product is thermodynamically stable against conversion to calcium carbonate by carbon dioxide in atmospheric air.

To validate that the mineral-like product is indeed stable, long-term stability testing was initiated and will be continued for 2 years. The experimental test procedure was presented in Appendix A. Briefly, the aging test procedure consists of the following steps:

- C One hundred grams of filter press solids (percent moisture determined) were placed in 1 L of effluent solution (in HDPE bottles). Triplicate test slurries were prepared.

- C The slurries were shaken for 24-hours, the pH and E_H were determined, and solution samples were extracted, preserved, and submitted to MSE-HKM for analytical characterization. These samples are considered time zero for the aging demonstration.
- C Each sample bottle was placed so that air could be sparged into the slurry at 10 mL/min. Solution pH, E_H , and temperature are presently being monitored monthly.
- C The solubility of the solids will be determined after 1 and 2 years of exposure.

The time zero analytical results are presented in Table 7-11.

7.2.3 X-ray Diffraction

The solids from the thickener overflow water were subjected to x-ray diffraction analysis. The results showed that solids formed were similar to the scrubber blowdown water solids. The x-ray diffraction patterns for the thickener overflow water solids and the scrubber blowdown water are superimposed in Figure 7-7.

7.3 Mineral Hill Mine 1,300' Portal Results

The removal of arsenic from Mineral Hill Mine 1,300' Portal groundwater by the mineral-like precipitation technology was very effective [e.g., the effluent water from the settler (after only 1 hour of continuous operation) was < 10 ppb (one sample was 25 µg/L, the goal was to remove the arsenic to below 50 ppb)]. The experimental results are summarized in Table 7-12. The input water composition and the final effluent water from the treatment system is presented in Table 7-

13. The solution pH, E_H , and temperature data are summarized in Table 7-14.

The removal of arsenic from Mineral Hill Mine groundwater is dependent on the addition of the proper amount of lime, see Figure 7-8. The solubility of arsenic as APHAP is depicted in this figure. The data used to generate the figure are based on the standard free energy of formation of APHAP, as determined by Twidwell, et al (Ref. 7). Note that less than 0.10 g/L lime should be required for effective removal of arsenic.

The demonstration test was conducted using three different lime addition rates shown on the diagram in Figure 7-9 [i.e., the treatment started at 1 g/L lime (for 32 hours), was subsequently decreased to 0.5 g/L (after 32 hours), then was decreased to 0.25 g/L for the remainder of the demonstration]. Also note in Figure 7-9 that the solution pH was still above 10 even at a lime addition rate of 0.25 g/L (solids must be formed at a pH of 10 or greater to ensure that the product is stable for long-term storage).

7.3.1 Batch Tests

Residence time, effect of P/As mole ratio, and effect of hydrated lime content were determined in a series of large-scale batch tests. The procedure and experimental results are presented below.

7.3.1.1 Residence Time

The residence time was determined by flowing process solution into a single reactor and measuring the arsenic concentration as a function of fill time. Two tests were conducted; one at a flow rate of 1 gallon of groundwater/minute and the second at a flow rate of 2 gallons of groundwater/minute. The following parameters were held constant for both tests: P/As mole ratio was 20, and the hydrated lime concentration was 0.5 g/L. The

results are presented in Table 7-15. The arsenic content was lowered to below the project goal (< 50 ppb) in less than 15 minutes residence time.

7.3.1.2 Effect of P/As Mole Ratio

Reactor vessels 102, 103, 107 were used to conduct 75-gallon batch tests. Each vessel was filled with Mineral Hill Mine groundwater and phosphoric acid was added to give P/As mole ratios of 10, 20, and 200. Hydrated lime was then added to the three vessels (each agitated) at the same time, and samples were collected as a function of time. The experimental results are presented in Table 7-15. The experimental results show that the higher the P/As mole ratio in the starting water, the lower the achievable arsenic content in the treated water. However, all the mole ratios investigated showed arsenic removal from the solution to below 50 µg/L in less than 5 minutes of reaction time.

7.3.1.3 Effect of Hydrated Lime Content

Reactor vessels 102, 103, 107 were used to conduct 75-gallon batch tests. Each vessel was filled with Mineral Hill Mine groundwater and phosphoric acid was added to provide a P/As mole ratio of 10. Hydrated lime was then added to the three vessels (each agitated) at the same time and samples were collected as a function of time. The experimental results are presented in Table 7-16. The experimental results show that hydrated lime concentrations between 0.1 g/L and 0.5 g/L are required. The large-scale continuous test demonstrated effective arsenic removal at a lime content of 0.2 g/L.

7.3.1.4 Solid Characterization

Solids were collected from the settler at the end of the test run. The percent solids in the settler bottoms were $1.2 \pm 0.1\%$. One liter of the aliquot samples was split from the slurries and used for settling rate studies (see Section

7.3.3). Each settler bottom slurry was filtered. The filtrates were saved and used to set up the long-term stability tests (see Section 7.2.3) and replace the solution that evaporates with time from the long-term aging samples. The solids were saved for characterization studies, including elemental characterization, x-ray diffraction, scanning electron microscopy (and energy dispersive spectroscopy), and long-term stability during storage.

7.3.1.5 Toxicity Characteristic Leaching Procedure

The TCLP was performed on the composite solids produced at the end of the treatment series. Total metals concentration and TCLP results are presented in Table 7-17. Note, product solids from the treatment sequences passed the TCLP test; therefore, these solids are considered to be nonhazardous with respect to handling and land disposal.

7.3.1.6 Long-Term Stability

The need for long-term stability testing was presented previously in Sections 3.1 and 7.1.4, the solids that are produced by other technologies (lime precipitation and ferrihydrite adsorption) may not be stable for long-term outdoor storage. The mineral-like precipitation technology solves the storage problem because the product is thermodynamically stable against conversion to calcium carbonate by carbon dioxide in atmospheric air.

To validate that the mineral-like product is indeed stable, long-term stability testing was initiated and will be continued for 2 years. The experimental test procedure was presented in Appendix A. Briefly, the aging test procedure consists of the following steps:

- C One hundred grams of filter press solids (percent moisture determined) were placed in 1-liter of effluent solution (in HDPE

bottles). Triplicate test slurries were prepared.

- C The slurries were shaken for 24-hours. The pH and E_H were determined and solution samples were extracted, preserved, and submitted to MSE-HKM for analytical characterization. These samples are considered time zero for the aging demonstration.
- C Each sample bottle was then set up so that air could be sparged into the slurry at 10 mL/min. Solution pH, E_H , and temperature are presently being monitored monthly.
- C The solubility of the solids will be determined after 1 and 2 years of exposure.

The time zero analytical results are presented in Table 7-18. For comparison the ferrihydrite technology results are also presented in Table 7-18. Note that the mineral-like precipitation is equal to, or more effective for removing all the quoted elements, especially arsenic.

7.3.2 Settling Rate

The envisioned utilization of the mineral-like precipitation technology is that the precipitated solids will be clarified in a thickener. The overflow water will be the discharge water. The underflow slurry from the thickener will be pumped to a storage pond. The separation of solids requires a properly sized thickener. Therefore, a preliminary evaluation of settling rate was conducted using the Kynch method. Refer to the MWTP Activity III, Project 9—Mineral-Like Precipitation Studies by Dr. Larry Twidwell for a description of the Kynch method and the results of the settling rate tests (Ref. 11).

The required thickener size is approximately $1,154 \cdot M$ (square meters of thickener surface area, where M is the solids flow rate in metric tons per hour). A sizing exercise is presented below for a contaminated Mineral Hill Mine water feed rate of 300 gallons per minute (gpm) containing 500 ppb arsenic. This sizing exercise is based on a settling data that did not utilize any flocculant. Flocculant addition would enhance the settling rate.

The process will produce 0.00078 metric ton per hour (MT/hr) of product solids at the assumed water flow rate [P/As mole ratio = 10, lime requirement 1.5 times the stoichiometric requirement for $\text{Ca}_{10}(\text{As}_{0.11}\text{P}_{0.89}\text{O}_4)_6(\text{OH})_2$].

A thickener of $1154 \text{ m}^2/\text{MT/hr} \cdot 0.00078 \text{ MT/hr} = 0.9 \text{ m}^2$ would therefore be required.

The diameter of the thickener would be 1.1 m (3.5 ft).

The required thickener diameter would be 3.5 ft. The smallest industrially available thickener is 4 ft (diameter). Solid/liquid separation does not appear to be a problem.

7.3.3 X-ray Diffraction

The x-ray diffraction pattern for the product from the Mineral Hill Mine 1,300' Portal groundwater is presented in Figure 7-10. This pattern shows that the product is primarily calcium carbonate. The arsenic content is ~ 0.02%, therefore, the APHAP in the demonstration product would not be expected to be seen by x-ray diffraction.

7.4 Alumina Adsorption Results

Four tests were conducted treating ASARCO thickener overflow water and one test treating Mineral Hill Mine 1,300' Portal water. Complete analytical results for the alumina adsorption tests are presented in Appendix B.

7.4.1 ASARCO Pilot Analytical Results

7.4.1.1 Feed Water Arsenic and pH

During the demonstration using alumina adsorption with microfiltration, it should be noted that dissolved arsenic concentration varied. Examples of this variation can be observed in Figures 7-11, 7-12, and 7-13. Consequently, none of the data in Appendix B for the ASARCO tests was qualified in MSE-HKM's data validation report.

There was an inverse correlation between pH and arsenic concentration. As pH decreased from thickener overflow water, arsenic concentration increased.

Dissolved arsenic in aqueous solution exists as the arsenite and arsenate salts, which are highly soluble over a wide pH range with the exception of the calcium salt. The decrease in arsenic solubility with increased pH was likely due to adsorption of the arsenite and arsenate anions onto suspended particles in the feed water, and/or coprecipitation of these anions with other species. The average pH of the ASARCO feed water samples was 7, while the average ZeeWeed process tank was 4. Since lower pH is related to a higher dissolved arsenic content, it is likely that there was further dissolution of the arsenic when the feed water entered the lower pH process tank. The activated alumina was likely exposed to a higher dissolved arsenic concentration than feed water analysis would suggest, and pilot data must be evaluated on the basis of final permeate quality, rather than percent removal basis.

7.4.1.2 ASARCO Feed Water Arsenic Speciation

Results from the two arsenic speciations performed on oxidized ASARCO water are

shown in the Appendix B. Analysis of the first sample taken shows no oxidation, while analysis of the second sample shows complete oxidation of arsenic from + 3 to the + 5 state.

7.4.1.3 Trial 1 Test 1

Dissolved arsenic and pH of the feed and permeate are plotted in Figure 7-11. There are two anomalous dissolved arsenic analyses for the permeate. The dissolved arsenic concentration for the permeate sample was measured at 4.3 ppm. It was hypothesized that the high arsenic level of this sample was due to poor adsorption onto activated alumina since the ZeeWeed was measured at 2 ppm for pH 4, the dissolved arsenic content of the permanent sample should have been near this level or lower because the process tank pH was 7.6. However, the dissolved arsenic content for the permeate sample was measured at 3.16 ppm at a pH of 3.9. Since the dissolved aluminum analysis for this permeate sample was high, there was possible contamination of the sampling equipment from the TSS sampling event.

The average dissolved arsenic content of the permeate was 1.42 ppm at an average pH of 4.1. The average dissolved arsenic measured in the feed was 1.46 at an average pH of 4.7.

For permeate sample number PLA1-148A, the dissolved arsenic analysis was 2.28 ppm, while the total arsenic was 2.38 ppm. All samples analyses for the alumina adsorption tests are provided in Appendix B. These two values are in close agreement (5% RPD), indicating that only dissolved arsenic passes through the ZeeWeed membrane.

7.4.1.4 Diafiltration 1a

Dissolved arsenic and pH of the feed and the permeate from the Diafiltration Trial 1 Test 1 can be observed in Figure 7-12. The dissolved arsenic analysis of 2.55 ppm at a pH of 8.9 for

sample number is high since the preceding sample from the same feed tank has a dissolved arsenic analysis of 0.4 ppm at a pH of 8.3.

The average dissolved arsenic concentration in the feed during the diafiltration was 0.09 ppm at pH 12. The average permeate dissolved arsenic concentration was 0.18 ppm at pH 12, higher than the dissolved arsenic in the feed, as expected during diafiltration. However, it should be noted that the permeate dissolved arsenic concentration was 0.219 ppm at the start of diafiltration, whereas it was 2.3 ppm at the end of the adsorption trial. The lower concentration of dissolved arsenic in the sample would seem to indicate that arsenic had desorbed from the activated alumina during recirculation at pH 12, and the dissolved arsenic in the process tank had coprecipitated with or adsorbed onto some other compound at the high pH of diafiltration and therefore, had not passed through the membrane during diafiltration. Since the total arsenic concentration in the ZeeWeed process tank during diafiltration is not known, the amount of arsenic desorbed at high pH cannot be calculated.

7.4.1.5 Trial 2 Test 1

Dissolved arsenic and pH of the feed and permeate from Trial 2 of Test 1 are plotted in Figure 7-13.

During this trial, the dissolved arsenic content of the permeate stream rose continuously, while the pH was relatively constant at 3.9. The amount of arsenic that exited in the permeate during this trial was calculated at 40,800 mg. This value was checked against the total amount of arsenic in the system. Calculated on the basis of dissolved arsenic in the feed, the amount of arsenic that had been introduced to the system from the beginning of the test to the end of Trial 2, Test 1 was only

27,400 mg, which is less than the amount of dissolved arsenic that exited the system. This further supports the hypothesis that some of the arsenic that was nonsoluble in the feed dissolved in the low pH environment of the ZeeWeed process tank.

Arsenic that was desorbed from the alumina during preceding diafiltration coprecipitated with, or was adsorbed onto another precipitate at the high pH of diafiltration, and therefore, could not exit in the permeate during diafiltration. When the pH was dropped for Trail 2 of Test 1, the coprecipitated/adsorbed arsenic gradually redissolved but did not adsorb onto the alumina. As the arsenic redissolved, it passed through the ZeeWeed membrane and exited in the permeate.

7.4.1.6 Diafiltration 1b

Dissolved arsenic concentration and pH of the feed and the permeate from the diafiltration can be observed in Figure 7-14. The average dissolved arsenic concentration in the feed was 0.088 ppm at pH 11.8, and the average dissolved arsenic concentration in the permeate was 0.318 ppm at pH 12. The dissolved arsenic was higher in the permeate than in the feed during diafiltration. The dissolved arsenic concentration in the permeate after recirculation of the process tank at pH 12 was lower than the dissolved arsenic concentration in the permeate at the end of the preceding adsorption step. The first permeate sample of the diafiltration had a concentration of 0.315 ppm dissolved arsenic, while the last permeate sample in the preceding adsorption step had a dissolved arsenic concentration of 7.5 ppm. This suggests that the high pH of the diafiltration step caused both the arsenic that had adsorbed from the alumina and the arsenic in the process tank volume to come out of solution.

7.4.1.7 Test 2

Dissolved arsenic concentration and pH of the feed and permeate from Test 2 is shown in Figure 7-15. The dissolved arsenic in the first Test 2 permeate sample was higher than the dissolved arsenic in the permeate at the end of the preceding diafiltration, and it increased in the subsequent sample. This suggests that the arsenic had precipitated out in the ZeeWeed process tank at pH 12 during diafiltration, redissolved, and passed through the membrane at the lower pH of Test 2. The alumina concentration was increased to 30 g/L. Dissolved arsenic in the permeate was approximately 270 ppb at an average pH of 3.9. A higher concentration of alumina was successful in reducing the dissolved arsenic concentration in the process tank from its previous level.

The average sulfate concentration was 2,160 ppm in the feed and 1,730 ppm in the permeate indicating that some of the sulfate adsorbed onto the alumina. Consequently, the capability of the alumina to adsorb arsenic was reduced.

7.4.1.8 Test 3

Dissolved arsenic and pH of the feed and permeate from Test 3 are plotted in Figure 7-16. Diafiltration was not performed between Tests 2 and 3, and the purpose of running Test 3 was to determine how the membrane would perform at a high solids level (60 g activated alumina per L). The membrane performance was reported above in the description of the data in Figure 7-16.

Throughout Test 3, the feed water dissolved arsenic analysis fluctuated depending on the pH of the feed water, increasing as the pH increased.

The average dissolved arsenic concentration of the permeate in Test 3 was 183 ppb at an average pH of 4.2.

The average sulfate concentration was 2,330 ppm in the feed and 1,790 ppm in the permeate. The arsenic adsorption capacity of the alumina may have been reduced by adsorption of sulfate.

7.4.1.9 Test 4

Dissolved arsenic and pH of the feed and permeate can be observed in Figure 7-17. The feed water for Test 4 was not treated with KMnO_4 for oxidation of As(III) to As(V).

The average dissolved arsenic concentration in the feed was 963 ppb at a pH of 10.3. The average dissolved arsenic concentration in the permeate was 334 ppb at a pH of 4.1.

The average sulfate concentration was 2,500 ppm in the feed and 1,940 ppm in the permeate, and the capability of the alumina to adsorb arsenic may have been reduced due to the adsorption of sulfate.

7.4.2 Mineral Hill Mine Water

7.4.2.1 Pilot Analytical Results

Dissolved arsenic and pH of the feed and permeate from the test on Mineral Hill Mine Water can be seen in Figure 7-18. The average dissolved arsenic concentration in the feed was 446 ppb at a pH of 4.2. The arsenic in the feed was completely dissolved (total and dissolved analyses were within 5% RPD). The average dissolved arsenic concentration in the permeate was 21 ppb at a pH of 3.8.

The average sulfate concentration was 236 ppm in the feed and 162 ppm in the permeate. The sulfate concentration in the Mineral Hill Mine water was much lower than in the ASARCO water, and the amount of sulfate adsorbed per gram of alumina was lower in the Mineral Hill Mine test.

7.4.2.2 Diafiltration

Dissolved arsenic and pH of the feed and permeate is shown in Figure 7-19. The dissolved arsenic concentration in the permeate was higher during diafiltration than during the preceding adsorption phase, indicating there was some desorption of arsenic from the activated alumina. The total amount of arsenic introduced to the ZeeWeed process tank was approximately 9,900 mg, based on the dissolved arsenic analysis of the feed. The total amount of arsenic that exited in the permeate during diafiltration was approximately 430 mg.

The dissolved arsenic in the permeate rose at the beginning of the diafiltration and then declined steadily although the feed water had a higher arsenic concentration than the process tank. The reason for the low initial concentration is not known. One hypothesis for the steady decrease is that there was precipitation of other species at the high pH of the process tank (pH 11.7) and arsenic which had desorbed from the alumina subsequently adsorbed onto these precipitated species.

7.5 Ferrihydrite Adsorption

7.5.1 ASARCO Analytical Results

For removal of arsenic in ASARCO thickener overflow water, two separate parameters were used. An iron to arsenic mole ratio of both 8 and 10 was used for ferrihydrite adsorption. The removal of arsenic from thickener overflow water is dependent on the amount of iron inputted into the system. Ferrihydrite adsorption technology was performed at the East Helena site using their current existing facility.

7.5.1.1 Low Iron Demonstration

Using an iron to arsenic mole ratio of 8, arsenic concentrations were lowered from 6.3 ppm to 100 ppb at pH of 7. Ferrihydrite adsorption was effective for arsenic removal, however, the established drinking water standard of 50 ppb was never achieved at this iron to arsenic mole ratio.

The analytical results can be observed in Table 7-19.

7.5.1.2 High Iron Demonstration

Increasing the iron content was very effective for removal of arsenic from ASARCO thickener overflow water. Concentrations were lowered from 6.3 ppm to less than 20 ppb. The input water composition and the final effluent results are summarized in Table 7-20.

7.5.2 Mineral Hill Mine 1,300' Portal Water

7.5.2.1 Analytical Results

For Mineral Hill Mine water, a pilot-scale process was constructed for the ferrihydrite adsorption technology.

The removal of arsenic using Mineral Hill Mine water by ferrihydrite adsorption was very effective. Results indicate arsenic concentrations were lowered from 600 ppb to less than drinking water standards of 50 ppb. The arsenic to iron mole ratio used for this demonstration was 10, which proved to be sufficient. Results can be seen in Table 7-21. Complete analytical results for the ferrihydrite adsorption tests are provided in Appendix B.

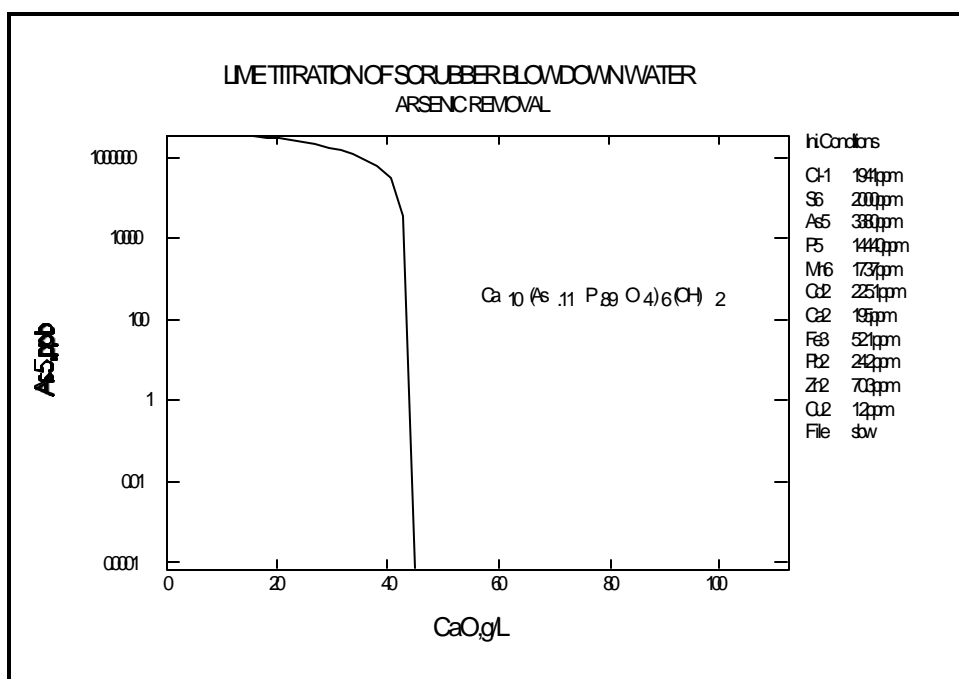


Figure 7-1. Lime titration of scrubber blowdown water: arsenic removal as a function of added lime.

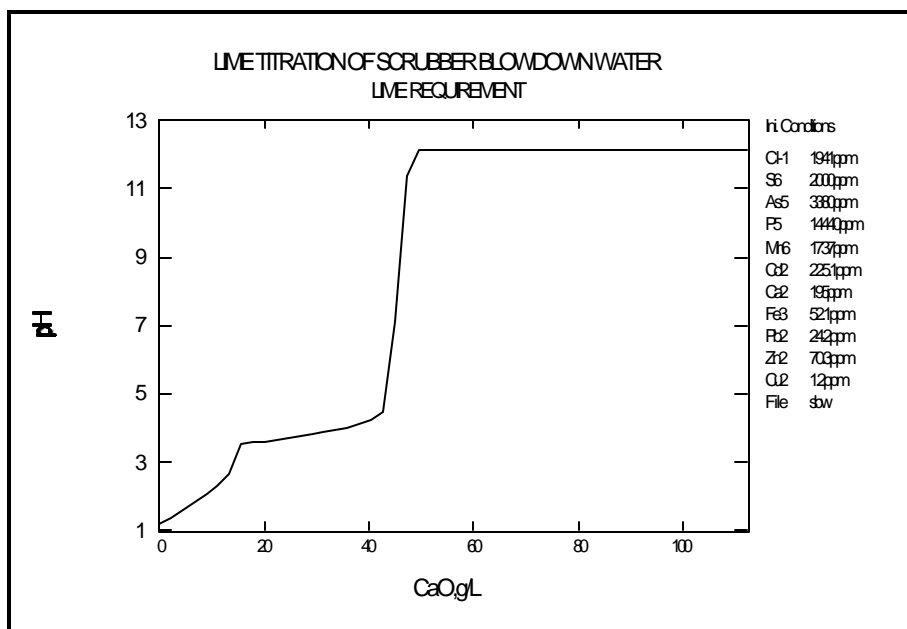


Figure 7-2. Lime titration of scrubber blowdown water: pH as a function of added lime.

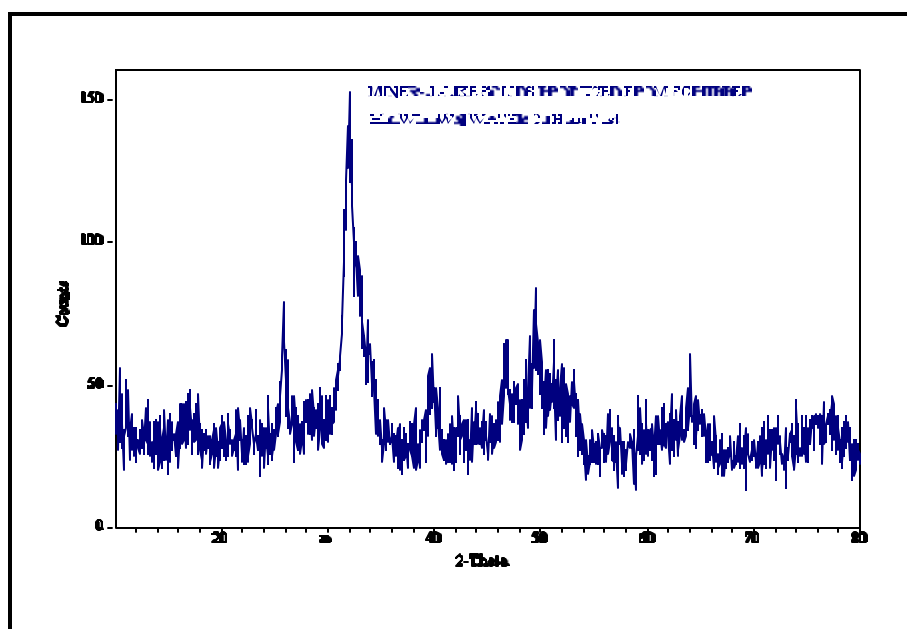


Figure 7-3. X-ray diffraction pattern for ASARCO scrubber blowdown water.

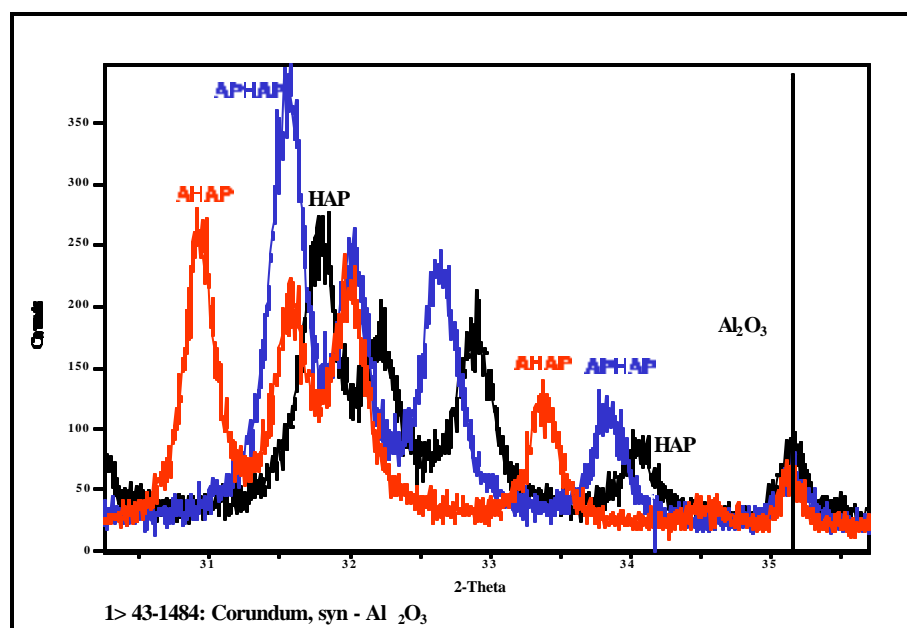


Figure 7-4. X-ray diffraction patterns for HAP, AHAP, and APHAP.

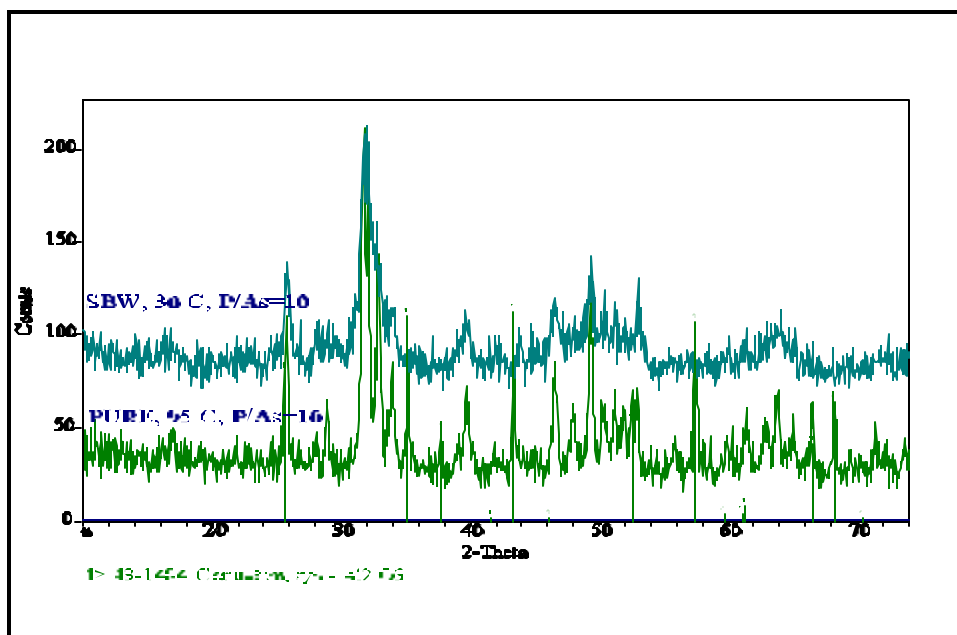


Figure 7-5. X-ray diffraction pattern for ASARCO scrubber blowdown water solid product superimposed on APHAP (both containing approximately 2-3% arsenic)

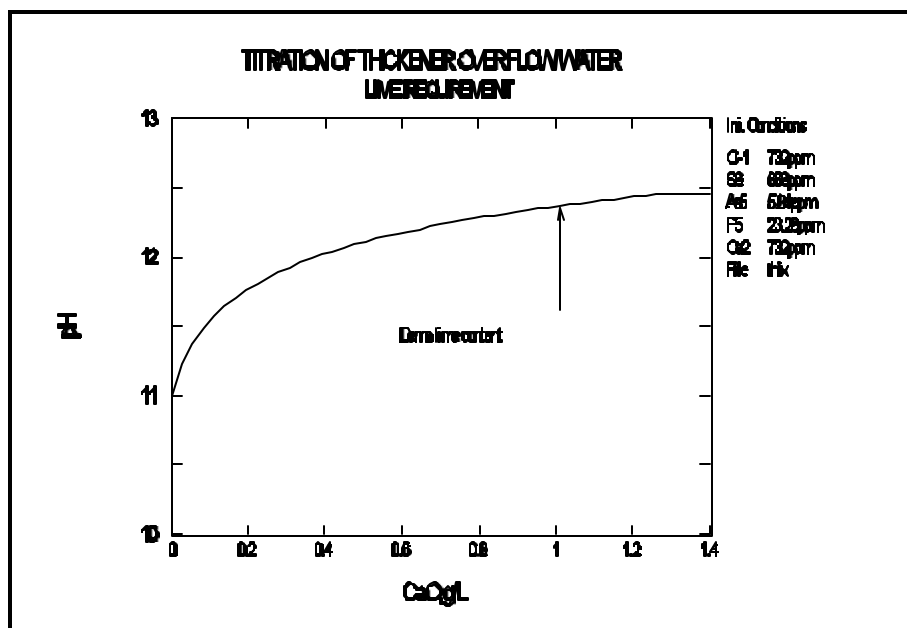


Figure 7-6. Hydrated lime titration of ASARCO water treatment thickener overflow water: pH as a function of added lime.

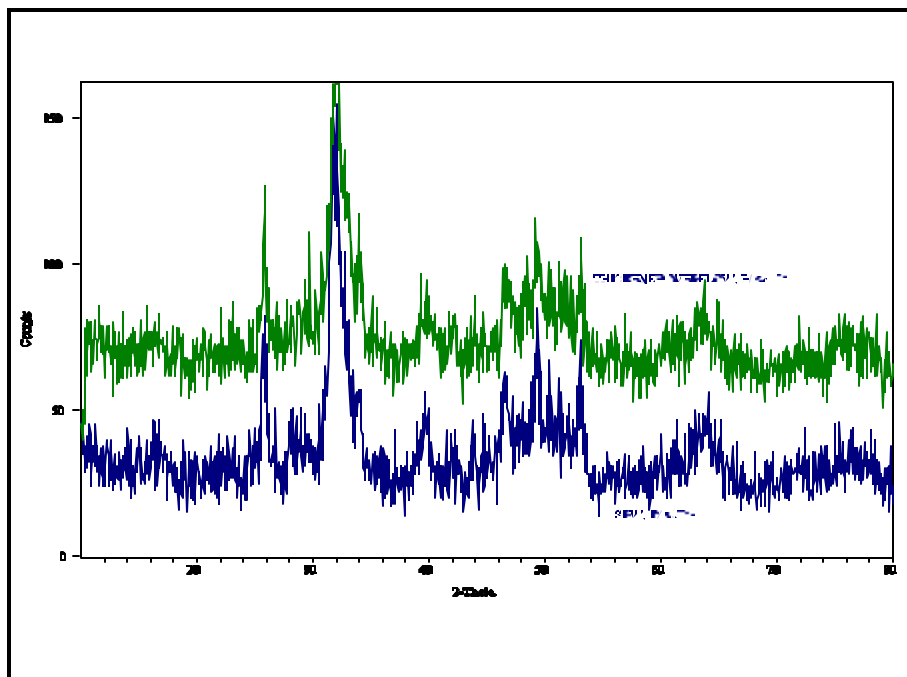


Figure 7-7. X-ray diffraction pattern for ASARCO thickener overflow water solid product superimposed on scrubber blowdown water solid product.

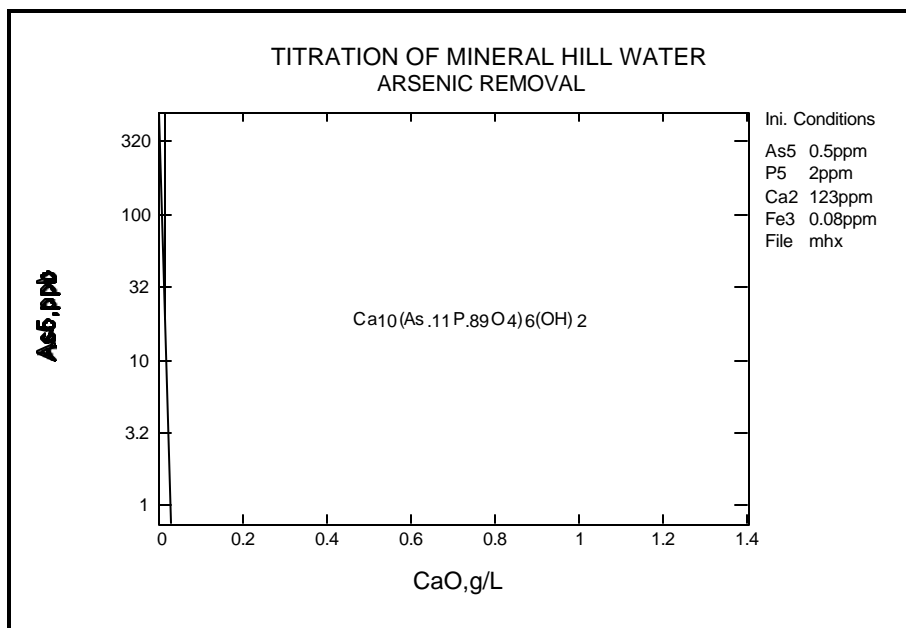


Figure 7-8. Hydrated lime titration of Mineral Hill Mine 1,300' Portal groundwater: arsenic removal as a function of added hydrated lime.

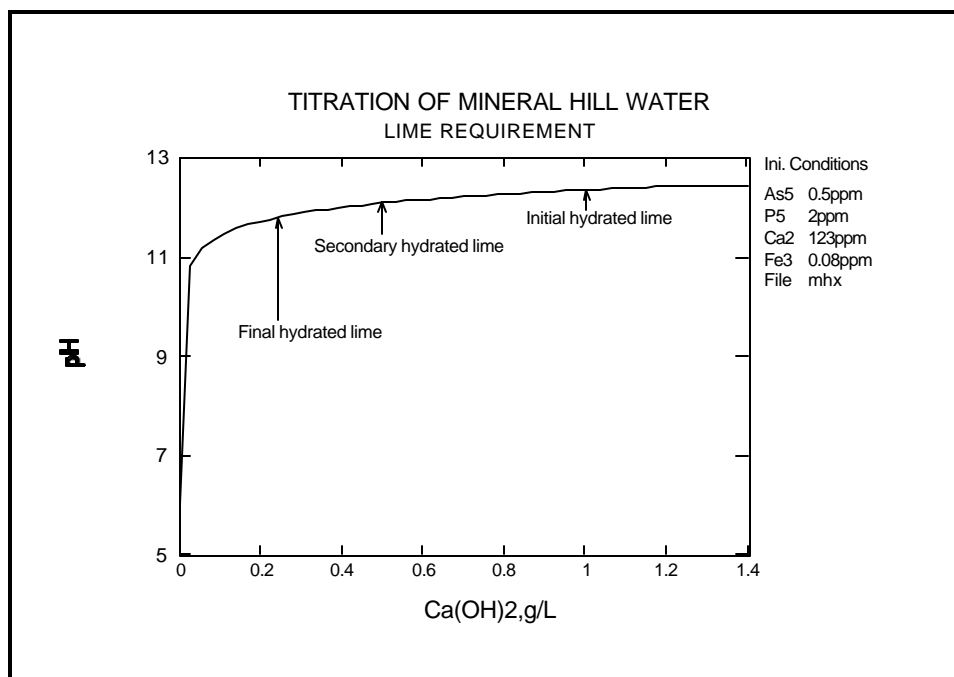


Figure 7-9. Hydrated lime titration of Mineral Hill Mine 1300' Portal groundwater: pH as a function of added hydrated lime.

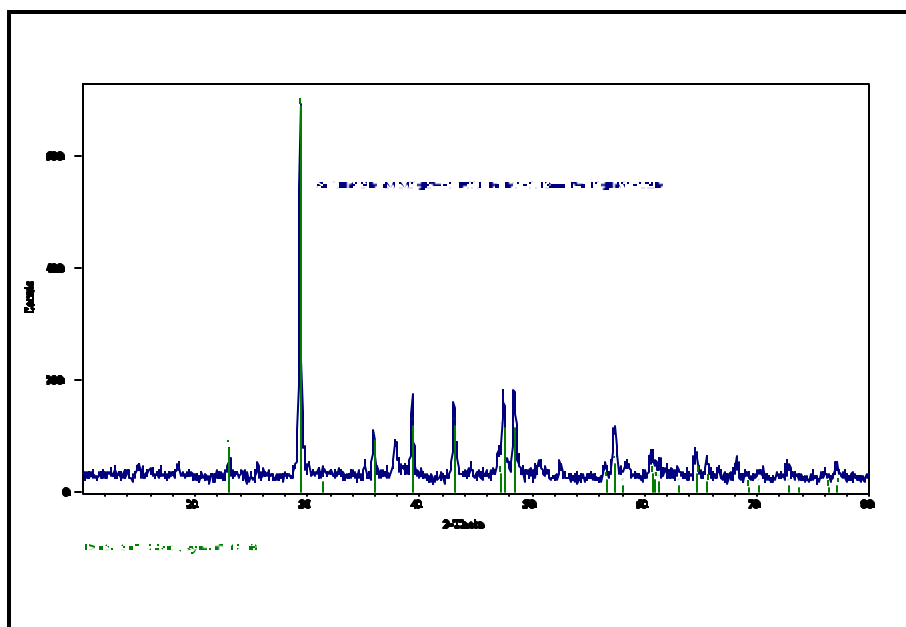


Figure 7-10. X-ray diffraction patterns for Mineral Hill Mine 1,300' Portal ASARCO thickener overflow water solids.

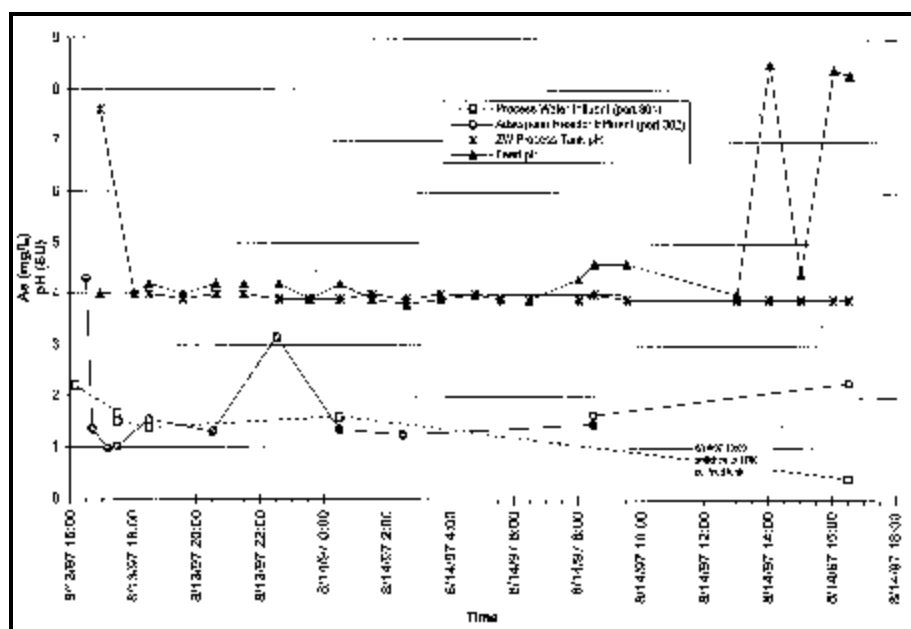


Figure 7-11. ASARCO-Trial 1 of Test 1 (activated alumina at 5 g/L). Dissolved arsenic and pH.

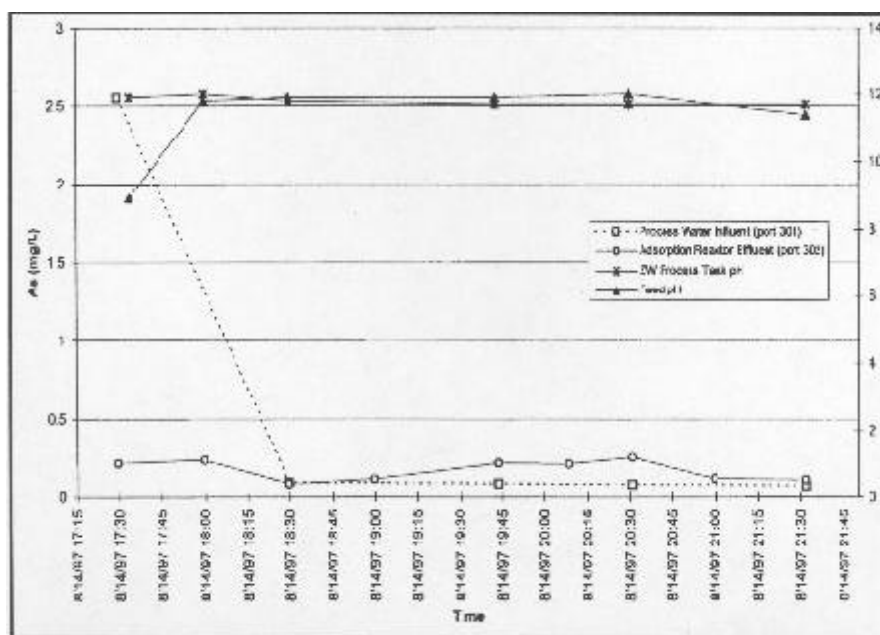


Figure 7-12. ASARCO dialfiltration after Trial 1 of Test 1 (activated alumina at 5 g/L). Dissolved arsenic.

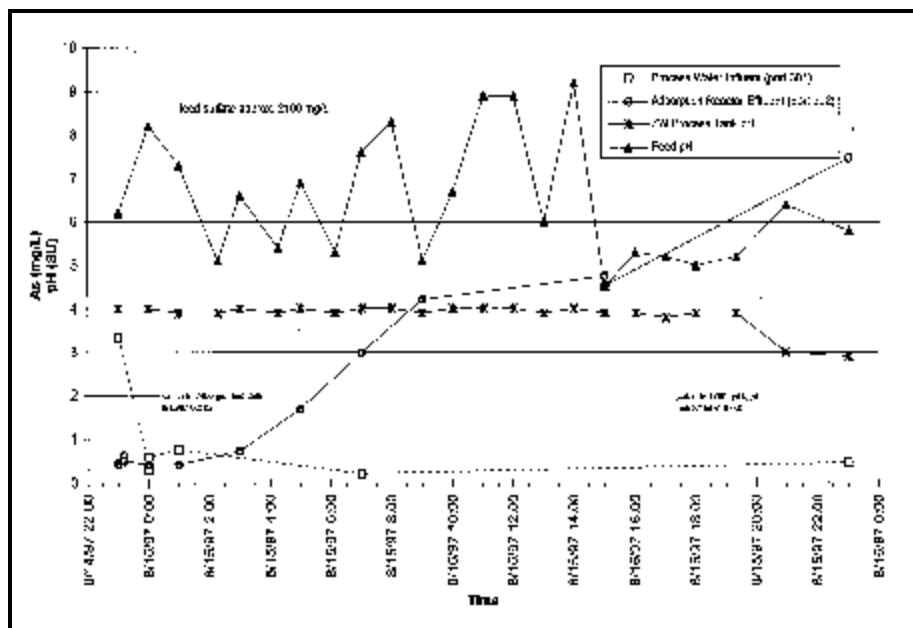


Figure 7-13. ASARCO—Trial 2 of Test 1 (activated alumina at 5 g/L). Dissolved arsenic and pH.

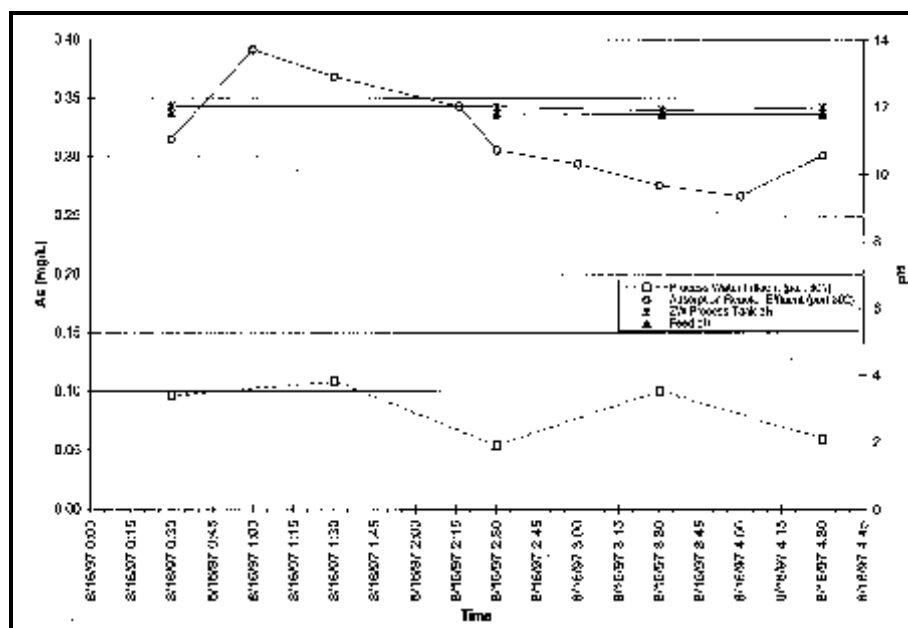


Figure 7-14. ASARCO diafiltration after Trial 2 of Test 1 (activated alumina at 5 g/L). Dissolved arsenic and pH.

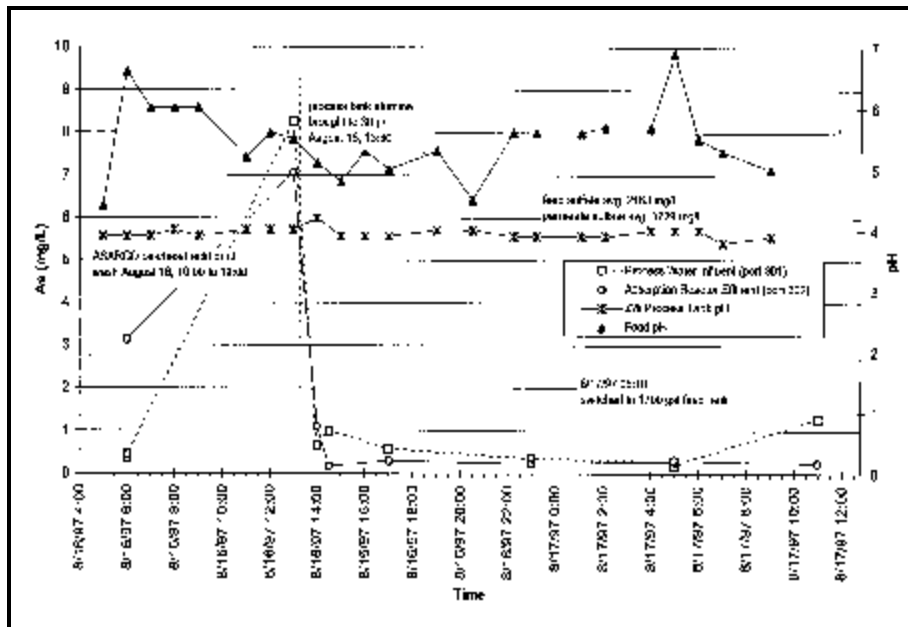


Figure 7-15. ASARCO Test 2 (activated alumina at 30 g/L). Dissolved arsenic and pH.

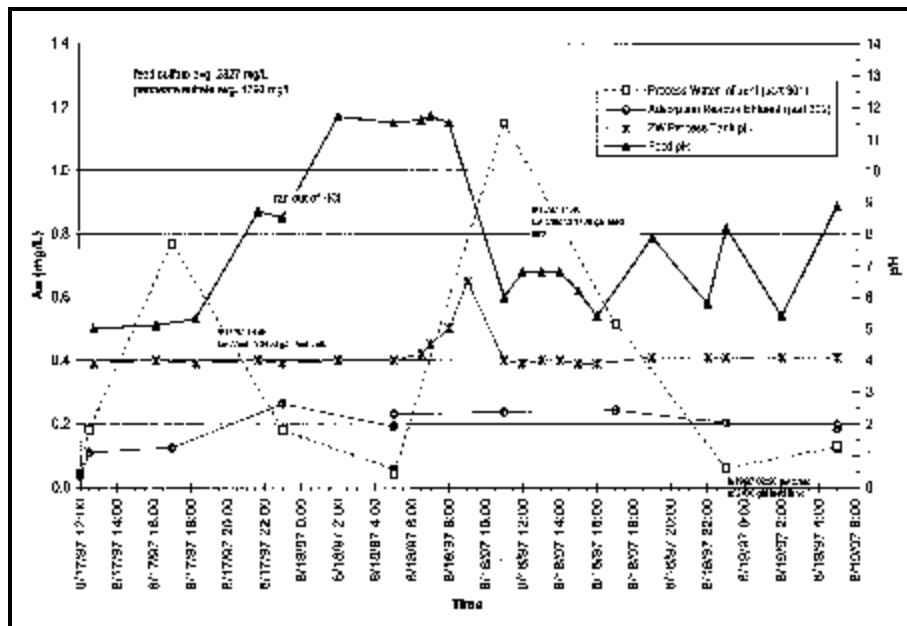


Figure 7-16. ASARCO Test 3 (activated alumina at 60 g/L). Dissolved arsenic and pH.

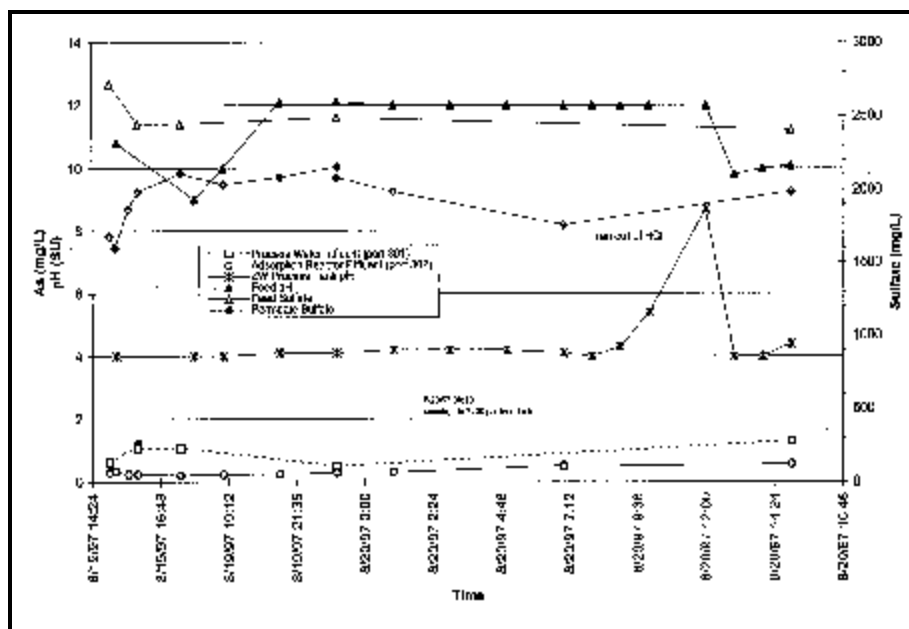


Figure 7-17. ASARCO Test 4 (activated alumina at 20 g/L noKMnO₄). Dissolved arsenic and pH.

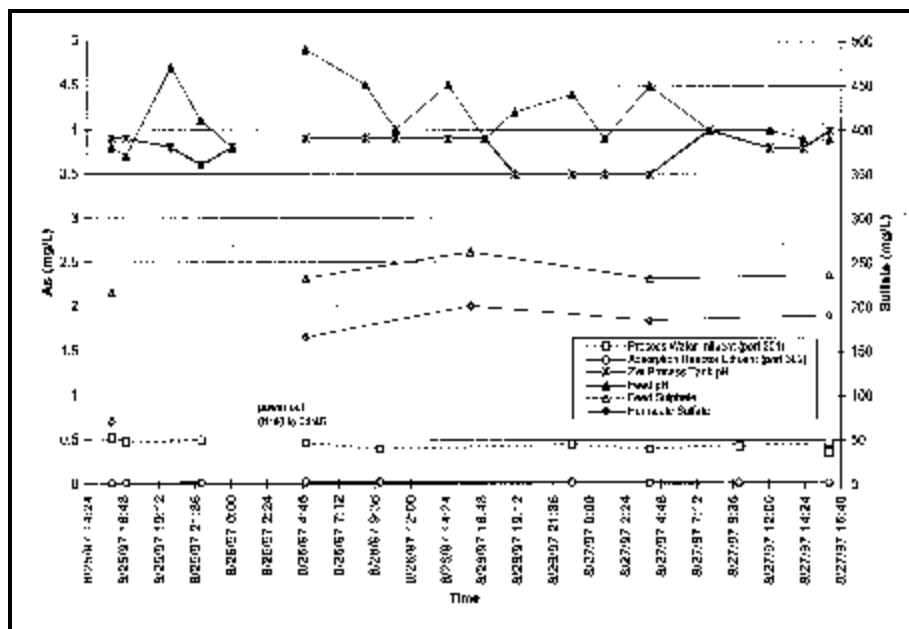


Figure 7-18. Mineral Hill Mine water (activated alumina at 20 g/L). Dissolved arsenic and pH.

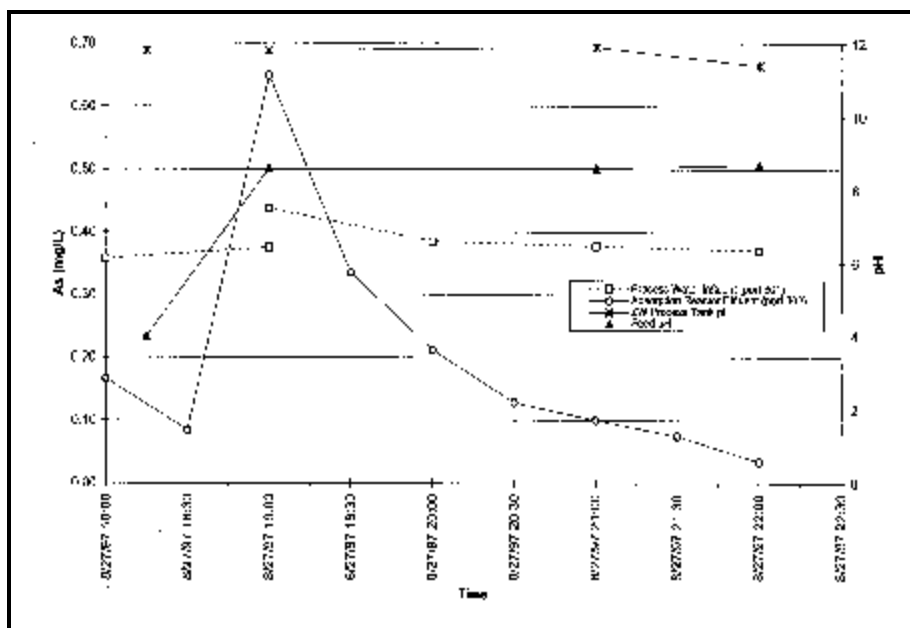


Figure 7-19. Diafiltration after Mineral Hill Mine water (activated alumina at 20 g/L). Dissolved arsenic and pH.

Table 7-1. Summary of Laboratory Test Results (P/As Mole Ratio= 7)

Test ¹	Average Residence Time/Vessel min.	Conditions			[As], µg/L						Final Composite
		Solution pH	General	Initial	V1		V2		V3		
					Hours	[As]	Hours	[As]	Hours	[As]	
Min. Hill (Test BS 3)	38	12.4	Seed 3.4% into vessel-1. Slurry feed rate 21 cc/min. Solution feed rate 5 cc/min. P/As mole ratio 7000 ² .	454	1	1.7	1	2.0			5.1 (14 hrs) recovery= 98.9%
					4	8.2	4	1.7			
					8	5.2	8	3.2			
							14	2.2			
Min. Hill (Test BS 5)	39	12.4	Seed 1.6% into vessel-1. Slurry feed rate 20.0 cc/min. Solution feed rate 10 cc/min. P/As mole ratio 7.	468	1	41.8	1	29.3			11.7 (16 hours) recovery= 97.4%
					4	26.2	4	12.9			
					8	21.2	8	4.8			
					16	4.9	15	3.5			
Min. Hill (Test BS 7)	V1, V2= 33 V3= 20	12.4	Seed 0.5% into vessel-1. Slurry feed rate 20.7 cc/min. Solution feed rate 4.8 cc/min. P/As mole ratio 7.	455	4	16.2	4	26.2	4	10.1	18.5 (4 hours) recovery= 95.9%
Min. Hill (Test BS 8)	8-9	10 for 16 cc/min lime slurry feed; 12 for 22 cc/min	No seed, lime 0.76%. Lime feed rate 16.0 cc/min for first 2 hours, then 22 cc/min for 2 hours. Solution feed rate 20 cc/min. P/As mole ratio 7.	503.7, 506.8	2	8.2	2	4.9	2	11.8	
					4	19.2	4	7.8	4	7.7	
ASARCO (Test BS 10) scrubber blowdown	8-10	12.4	No seed, lime 10.0%. Lime feed rate 20.0 cc/min . Solution feed rate 40 cc/min. P/As mole ratio 7.	2,188 ppm	2	88.9	4	129.4	4	140.8	7.2 (4 hours) recovery= 99.9996+%
					4	162.0					
ASARCO (Test BS 4) scrubber blowdown	41	12.4	No seed, lime 1.0%. Lime feed rate 19.7 cc/min. Solution feed rate 4.6 cc/min. P/As mole ratio 7.	8,089 ppm	4	14.8	1	114.2			3.0 (14 hours) recovery= 99.999996+%
					8	24.4	1	9.2			
					14	188.4	8	8.3			
							14	26.7			

1. Analytical data presented in Appendix B.
2. Feed solution P/As ratio formulation error.

Table 7-2. Mineral-Like Precipitation Technology Applied to ASARCO Scrubber Blowdown Water: Final Effluent Concentrations

Sample ¹	SP ²	Time (hours)	pH	Concentration (mg/L)								
				As	Ca	Cd	Cu	Fe	Mn	P	Pb	Zn
MHA-128: Inlet	101	24	1.3	~ 3.3 gpl	195	215	1.3	35.6	1,786	48	4.1	69.3
MHA-129:P/As= ~ 5.5: Effluent	106	24	12.1	7-9 ³ µg/L	776	20	NA	0.07	0.10	9	0.02	11.4
MHA-112A: Inlet	101	3	1.1	~ 3.3 gpl	203	230	1.3	39.2	1,884	389	8.0	73.9
MHA-113:P/As= ~ 11.9: Effluent	106	3	12.4	6-9 ⁴ µg/L	754	10	< 0.26	0.07	0.10	7.7	< 0.02	0.0

1. P/As in the water entering the treatment system.

2. SP= sampling port: 101 inlet sampling port, 106 effluent sampling port.

3. Range for all 27-hour samples.

4. Range for all 3-hour samples.

Table 7-3. Mineral-Like Precipitation Technology Applied to ASARCO Scrubber Blowdown Water: Summary of Solution Conditions

Time (hours)	SP 101 Feed Water			SP 102 Phosphate Added			SP 103 Lime Tank			SP 104 Residence Tank			SP 105 Residence Tank			SP 106 Settler Discharge		
	pH	E _H ,mV	T°C	pH	E _H , mV	T°C	pH	E _H , mV	T°C	pH	E _H ,mV	T°C	pH	E _H ,mV	T°C	pH	E _H ,mV	T°C
1	1.5		26.0	1.2	590		12.2			12.2		33.0						
2	1.5		26.0	1.2	580		12.2				-95	33.0						
4	1.4		26.0	1.1	625	28.0	11.5		35.0	11.6		34.0						
8	1.5		28.0	1.1	610	28.0	11.5		35.0	11.8	-95	34.0						
12	1.5	630	24.0	1.2	625		11.4			11.4	-65	33.0	11.6			12.4	-95	31.0
24	1.3		26.0	1.0	615		11.8				-75	32.0						
RAISED PHOSPHATE																		
1	1.1		29.0	1.0		37.5	10.8	-55	37.0		-55	36.0						
2	1.0		29.0				12.2	-55	37.0		-70	36.0						
3	0.9	605	28.5				12.3	-65	37.0	12.3	-55	37.0	-55	36.0		12.4	-70	

Demonstration Test Conditions:

Water feed rate was 3.6-4.0 liters/min.

Phosphate feed rate was 70-75 cc/min (of 85% H₃PO₄) for treatment of 1665 gal scrubber blowdown water (SBW) (i.e., 27-hour test).

Phosphate feed rate was 150 cc/min (of 85% H₃PO₄) for treatment of 405 gal SBW (i.e., 3-hour test).

P/As mole ratio in the initial solution phase was nominally ~ 5.5 (varied between 5.0-6.0) for the 27-hour test.

P/As mole ratio in the initial solution phase was nominally ~ 11.9 (varied between 11.5-12.5) for the 3-hour test.

Lime addition rate was 2.4 L/min. of a 10 % lime slurry for the 27-hour test.

Lime addition rate was 4.0 L/min. of a 10 % lime slurry for the 3-hour test.

Table 7-4. Total Metals Concentration and TCLP Results for Product Solids from the Treatment of Scrubber Blowdown Water: P/As Mole Ratio~ 5.5

Sample	Description	As	Ba	Ca	Cd	Cr	Pb	Hg	Se	Ag
Concentration [mg/kg (ppm)]										
MHA-121	Total Metals	41,300	2.56	384,000	-	15.9	273	-	321	< 1.69
Concentration [mg/L (ppm)]										
MHA-121	TCLP	0.90	0.076	-	0.030	0.13	< 0.03	0.40	0.30	< 0.003
Reference	Maximum element concentration	5	100	-	1	5	5	0.2	1	5

Percent solids in the sample supplied to MSE-HKM for TCLP test: 35.6± 1.2%.
All TCLP tests were conducted by MSE-HKM in accordance with EPA ICP protocol.

Table 7-5. Total Metals Concentration and TCLP Results for Product Solids from the Treatment of Scrubber Blowdown Water: P/As Mole Ratio ~ 11.9

Sample	Description	As	Ba	Ca	Cd	Cr	Pb	Hg	Se	Ag
Concentration (mg/kg)										
MHA-138	Total metals	21,300	1.59	307,000	-	7.4	110	-	179	< 1.7
Concentration (mg/L)										
MHA-138	TCLP	82.1	0.068	-	0.127	0.065	< 0.03	0.37	0.24	< 0.003
MHA-138	TCLP	87.5	0.210	-	0.147	0.062	< 0.03	0.49	0.20	< 0.003
Reference	Maximum element concentration	5	100	-	1	5	5	0.2	1	5

Percent solids in the sample supplied to MSE-HKM for TCLP test: 30.4± 0.4%.
Composition of the solids: 2.7% As, 5.7% P, 23.0% Ca, 1.0% Mn, 0.09% Cd, 0.05% Zn, 0.01% Pb (Determined by fluorescence analysis by Ashe Analytics, Inc.)
All TCLP tests were conducted by MSE-HKM in accordance with EPA ICP protocol.

Table 7-6. Summary of Experimental Results for Long-Term Air Sparging of Ambient Temperature Precipitated Mineral-Like Products, ASARCO Scrubber Blowdown Water: Time= 0

Sample	Technology Used ¹	Elemental Concentration, µg/L										
		pH	Al	As	Cd	Cu	Pb	Mn	Hg	P	Ag	Zn
MHA-121-1	MLP, P/As= 5.5	12.5	< 20	4	< 5	3	40	< 4	459	2,310	4	37
MHA-121-2	MLP, P/As= 5.5	12.6	< 20	3	< 5	5	40	< 4	436	2,250	< 3	41
MHA-121-3	MLP, P/As= 5.5	12.7	< 20	4	< 5	2	50	4	471	2,460	< 3	44
MHA-139-1	MLP, P/As= 11.9	12.4	20	2	< 5	5	< 30	< 4	295	2,200	5	< 13
MHA-139-2	MLP, P/As= 11.9	12.4	30	4	< 5	2	< 30	< 4	283	2,720	4	< 13
MHA-139-3	MLP, P/As= 11.9	12.4	< 20	3	< 5	3	< 30	< 4	265	1,190	< 3	< 13

1. MLP= mineral-like precipitation. P/As mole ratio in the initial solution phase was nominally ~ 5.5 (varied between 5.0-6.0) for the 27-hour test; P/As mole ratio in the initial solution phase was nominally ~ 11.9 (varied between 11.5-12.5) for the 3-hour test. The solids placed under long-term aging were formed from the waters containing the different P/As ratios.

Table 7-7. Mineral-Like Precipitation Technology Applied to ASARCO Thickener Overflow Water: Summary of Arsenic Removal

Time (hours)	Treated gallons ¹	[As], µg/L					
		SP 101 Feed Water	SP 102 Phosphate Added	SP 103 Lime Tank	SP 104 Residence Tank	SP 105 Residence Tank	SP 106 Settler Discharge
1	285	85	320	250	84	93	210
8	705	220		28	7	17	2
8	705						11
16	1,185	235	100			6	6
16	1,185						8
16	1,185						8
16	1,185						15
16	1,185						7
Average residence time, minutes				66	66	66	390
		RAISED PHOSPHATE					
1	285	200	540	See Table 7-13 ²		4	4
12	945	140	420				4

Time (hours)	Treated gallons ¹	[As], µg/L					
		SP 101 Feed Water	SP 102 Phosphate Added	SP 103 Lime Tank	SP 104 Residence Tank	SP 105 Residence Tank	SP 106 Settler Discharge
12	945		347				4
20	1,425	380	540			4	13
20	1,425		570			4	4
20	1,425					4	3
20	1,425					4	3
20	1,425						12
20	1,425						12
Average residence time, minutes				65	65	65	380

1. Time zero taken to be after one volume displacement of water added, i.e., all tanks full; 225 gallons.
2. The required residence time for removal of arsenic from solution is less than 15 minutes, see Table 7-13.

Demonstration Test Conditions:

Water feed rate was 3.6-4.0 liters/min.

Phosphate feed rate was 200 cc/min (of 300 cc H₃PO₄/80 gallons deionized water) for treatment of first 1,185 gallons of wastewater.

Phosphate feed rate was 130 cc/min (of 3 liters H₃PO₄/80 gallons deionized water) for treatment of 1,425 gallons of wastewater.

Total P in the inlet water was ~ 5.8 mg/L

Total P/As mole ratio was 10 (ratio in solution phase was ~ 34) for first 1,185 gallons of wastewater.

Total P/As mole ratio was 100 (ratio in solution phase was ~ 615) for last 1,425 gallons of wastewater.

Lime addition rate was 365 cc/min of a 1% lime slurry for treatment of 2,600 gallons of wastewater.

Table 7-8. Mineral-Like Precipitation Technology Applied to ASARCO Thickener Overflow Water: Final Effluent Concentrations

Sample ¹	SP ²	Time (hours)	pH	Concentration, µg/L								Pb	Zn
				As	Ca	Cd	Cu	Fe	Mn	P			
MLA-209A: Inlet	101	20	11.5	~ 5.8 mg/L ³	732 mg/L	20	10	30	20	25 mg/L		< 20	< 9
MLA-210: P/As= 100: Effluent	106	20	12.1	3-13 ⁴	813 mg/L	< 4	10	50	10	4 mg/L		< 20	< 9

1. P/As in the water entering the treatment system.
2. SP= sampling port: 101 inlet sampling port, 106 effluent sampling port.
3. Total arsenic= 5.9 mg/L; Dissolved arsenic= 0.26 mg/L.
4. Range for all the 20 hr samples.

Table 7-9. Mineral-Like Precipitation Technology Applied to ASARCO Thickener Overflow Water: Summary of Solution Conditions

Time (hours)	SP 101 Feed Water			SP 102 Phosphate Added			SP 103 Lime Tank			SP 104 Residence Tank			SP 105 Residence Tank			SP 106 Settler Discharge		
	pH	E _H , mV	T°C	pH	E _H , mV	T°C	pH	E _H , mV	T°C	pH	E _H , mV	T°C	pH	E _H , mV	T°C	pH	E _H , mV	T°C
1	11.6	-55	24.5	10.5	-5		12.4				-85	24.0						
2	11.6	-60	24.5	10.2	-5		12.4				-75	24.0						
4	12.5	10	24.0	10.2	15		12.3				-60	23.5						

Time (hours)	SP 101 Feed Water			SP 102 Phosphate Added			SP 103 Lime Tank			SP 104 Residence Tank			SP 105 Residence Tank			SP 106 Settler Discharge		
	pH	E _H , mV	T°C	pH	E _H , mV	T°C	pH	E _H , mV	T°C	pH	E _H , mV	T°C	pH	E _H , mV	T°C	pH	E _H , mV	T°C
8	11.5	20	23.0	10.3	65		12.5			12.5	-20	23.0				11.5	10	22.0
12	11.6	-5		10.5	20		12.5				-50	21.0				12.4		
16	11.4		24.0	10.4	70		11.0				20	22.0				12.2		22.0
RAISED PHOSPHATE																		
1	9.0	-10	25.0	5.5	130.0		11.8	-45		11.8	-60							
2	11.1	-10	24.5	5.4	115.0		11.8	-40		11.8	-50	25.0						
4	11.3	-10	25.0	5.5	140.0		11.8	-45		11.8	-55	24.5						
8	11.1	40	23.0	5.5	165.0		11.9	-40		11.9	-45	23.0						
12	9.8		23.0	5.5	175.0		11.8				35	23.0						
16	11.1		25.0	5.5	130.0		11.8			11.8	-30	24.0				11.8	-20	24.0
20	11.0	(10)	24.5				11.7	-95		11.7	-90	24.5				11.7	-70	24.5

Solids in settler bottom at end of the second test was 6.2%

Demonstration Test Conditions:

Water feed rate was 3.6-4.0 liters/min.

Phosphate feed rate was 200 cc/min (of 300 cc H₃PO₄/80 gallons deionized water) for the first 16-hour test.

Phosphate feed rate was 130 cc/min (of 3 liters H₃PO₄/80 gallons deionized water) for the 20-hour test.

Total P in the inlet water was ~ 5.8 mg/L

Total P/As mole ratio was ~ 10 (ratio in solution phase was ~ 34) for the first 16-hour test.

Total P/As mole ratio was ~ 100 (ratio in solution phase was ~ 615) for the 20-hour test.

Lime addition rate was 365 cc/min. of a 1% lime slurry for both the 16 and 20-hour tests.

Table 7-10. Total Metals Concentration and TCLP Results for Product Solids from the Treatment of ASARCO Thickener Overflow Water

Sample	Description	As	Ba	Ca	Cd	Cr	Pb	Hg	Se	Ag
Concentration (mg/kg)										
MLA-218	Total metals	370	16.8	343,000	-	< 5.7	58.9	-	384	< 1.91
Concentration (mg/L)										
MLA-218	TCLP	3.87	0.100	-	< 0.005	0.019	< 0.03	0.008	0.49	< 0.006
Reference	Maximum element concentration	5	100	-	1	5	5	0.2	1	5

Sample	Description	As	Ba	Ca	Cd	Cr	Pb	Hg	Se	Ag
--------	-------------	----	----	----	----	----	----	----	----	----

Percent solids in the sample supplied to MSE-HKM: 29.3± 0.6%.

Composition of the solids: 0.033% As, 5.4% P, 23.0% Ca (Determined by fluorescence analysis by ASHE Analytics)

All TCLP tests were conducted by MSE-HKM in accordance with EPA ICP protocol.

Table 7-11. Summary of Experimental Results for Long-Term Air Sparging of Ambient Temperature Precipitated Mineral-Like Products, ASARCO Thickener Overflow Water: Time= 0

Sample	Technology Used	pH	Elemental Concentration, µg/L									
			Al	As	Cd	Cu	Pb	Mn	Hg	P	Ag	Zn
MHA-217-1	Mineral-like precipitation	10.5	< 20	4	< 5	6	< 30	< 4	< 0.1	1,660	< 3	< 13
MHA-217-2	Mineral-like precipitation	10.6	< 20	7	< 5	5	< 30	< 4	< 0.1	1,600	< 3	< 13
MHA-217-3	Mineral-like precipitation	10.6	< 20	4	< 5	4	< 30	< 4	< 0.1	1,560	< 3	< 13

Table 7-12. Mineral-Like Precipitation Technology Applied to Mineral Hill Mine 1,300' Portal Groundwater: Summary of Arsenic Removal

Time, hrs	Treated gallons ¹	[As], µg/L					
		SP 101	SP 102	SP 103	SP 104	SP 105	SP 106
		Feed Water	Phosphate Added	Lime Tank	Residence Tank	Residence Tank	Settler Discharge
1	285	470	470		5	6	6
1	285						6
1 ²	285	443	485			27	8
8	705	470				8	5
8	705						< 1
8	705						3
8	705						8
16	1,185	450	480			4	22
RAISED PHOSPHATE							
24	1,665	470	440	7	4	3	4
24 ²	1,665	448	411		318,319	< 4	< 4
32	2,145	460					4
32 ²	2,145	432					< 4
LOWERED LIME TO 0.5 g/L							
40	2,625	460				6	4
40	2,625	460					< 1
40 ²	2,625	398	411		< 4	< 4	< 4
48	3,105	460					5
48	3,105	420	460	11			6
48	3,105	460				7	7
48 ²	3,105	445	417,466	18		11	9
56	3,585	490				7	6
64	4,065	480					6
64 ²	4,065	426					11
LOWERED LIME TO 0.25 g/L							
68	4,305	450	440		9		25
68	4,305						4
68	4,305						7
68	4,305						4
68 ²	4,305	451	429495		10		5, 3
76	4,785	480				8	4
76 ²	4,785	453,506				10	8

Table 7-12. Mineral-Like Precipitation Technology Applied to Mineral Hill Mine 1,300' Portal Groundwater: Summary of Arsenic Removal

Time, hrs	Treated gallons ¹	[As], µg/L					
		SP 101	SP 102	SP 103	SP 104	SP 105	SP 106
		Feed Water	Phosphate Added	Lime Tank	Residence Tank	Residence Tank	Settler Discharge
84	5,100	490	450			13	2
84	5,100						< 1
84	5,100						2
84 ²	5,100		438436			13	4
Average residence time, minutes				65	65	65	380

1. Time zero taken to be after one volume displacement of water added, i.e., all tanks full; 225 gallons.
2. Analyses performed at Montana Tech

Demonstration Test Conditions:

Water feedrate was 3.6-3.8 liters/min.

Phosphate feed rate was 70 cc/min (of 1 cc H₃PO₄/gallon deionized water) for treatment of first 1,185 gallons of wastewater.

Phosphate feed rate was 70 cc/min (of 2 cc H₃PO₄/gallon deionized water) for treatment of 3,915 gallons of wastewater.

Total P/As mole ratio was approximately 10.6-12.9 for first 1,185 gallons of wastewater.

Total P/As mole ratio was approximately 21.2-36.4 for last 3,915 gallons of wastewater.

Lime addition rate (1 g/L) was 360-380 cc/minute of a 1% lime slurry for treatment of 2,145 gallons of wastewater.

Lime addition rate (0.5 g/L) was 180-190 cc/minute of a 1% lime slurry for treatment of 1,920 gallons of wastewater.

Lime addition rate (0.25 g/L) was 90-100 cc/minute of a 1% lime slurry for treatment of 795 gallons of wastewater

Table 7-13. Mineral-Like Precipitation Technology Applied to Mineral Hill Mine 1,300' Portal Groundwater Final Effluent Concentrations

Sample ¹	SP ²	Time, Hrs	pH	Concentration, µg/L								
				As	Ca	Cd	Cu	Fe	Mn	P	Pb	Zn
MLM-328: Inlet	101	48	8.2	420	125 mg/L	10	10	< 24	20	< 30	< 20	10
MLM-329: P/As= 10-20: Effluent	106	48	12.0	6-7 ³	314 mg/L	< 39	< 24	40	10	500	< 20	10
MLM-344: Inlet	101	68	7.6	450	119 mg/L	< 4	< DL	< 24	NA	380	< 20	40
MLM-346: P/As= 20: Effluent	106	68	12.0	4-7 ⁴	215 mg/L	40	< 26	< 242	NA	< 310	< 206	< 88

1. P/As in the water entering the treatment system.
2. SP= sampling port: 101 inlet sampling port, 106 effluent sampling port.
3. Range for all 48 hour samples.
4. Range for all 68 hour samples.

Table 7-14. Mineral-Like Precipitation Technology Applied to Mineral Hill Mine 1,300' Portal Groundwater: Summary of Solution Conditions

Time (hrs)	SP 101 Feed Water			SP 102 Phosphate Added			SP 103 Lime Tank			SP 104 Residence Tank			SP 105 Residence Tank			SP 106 Settler Discharge		
	pH	E _H , mV	T°C	pH	E _H , mV	T°C	pH	E _H , mV	T°C	pH	E _H , mV	T°C	pH	E _H , mV	T°C	pH	E _H , mV	T°C
1	8.2		18.0	8.0	230	18.0	12.6				25	18.0						
2	8.2		17.5	7.8	30		12.7				-35	18.0						
4	8.2		16.5	7.7	115		12.8				-15	18.0						
8	8.2		17.0	7.7	110		12.5				-10	17.0						
12	8.2		15.0	7.8	200		12.5				-50							
16	7.6		17.0				12.4	60			25	16.0						
RAISED PHOSPHATE (See note)																		
24	7.3		18.0				12.4	40			25	18.0						
32	8.2		15.0	7.4	175.0		12.4			12.2	25	15.0	12.4	25	16			
LOWERED LIME TO 0.5 g/L																		
40	7.5		15.0				12.0	35			25	14.8						
48	7.4		17.0				11.9, 12.1	3545		12.2	2535	16.0	12.3	25				
56	8.2		15.5	7.5	330.0		12.0					15.5						
64	7.4		16.5				12.1	80			55	15.5						
LOWERED LIME TO 0.25 g/L																		
69	7.4						11.5			11.8			11.9					
72	8.1	185	18.5	7.2	220.0		11.3			11.4	120	18.5	11.6			11.9		
82	8.1			7.2			11.2			11.1			11.1			11.7		
84	8.1		17.0	7.6	250.0		11.1				150	16.5						

Demonstration Test Conditions:

Water feedrate was 3.6-3.8 liters/min.

Phosphate feed rate was 70 cc/min (of 1 cc H₃PO₄/gallon deionized water) for the first 16 hours of the test.

Phosphate feed rate was 70 cc/min (of 2 cc H₃PO₄/gallon deionized water) for the remainder of the test.

Total P/As mole ratio was approximately 10.6-12.9 for first 16 hours of the test.

Total P/As mole ratio was approximately 21.2-36.4 for the remainder of the test.

Lime addition rate (1 g/L) was 360-380 cc/minute of a 1% lime slurry for the first 32 hours of the test.

Lime addition rate (0.5 g/L) was 180-190 cc/minute of a 1% lime slurry for the second 32 hours of the test.

Lime addition rate (0.25 g/L) was 90-100 cc/minute of a 1% lime slurry for the remainder of the test.

Table 7-15. Arsenic Concentration as a Function of P/As Mole Ratio

Sample Designation	Time, min	[As], µg/L		
		P/As= 10	P/As= 20	P/As= 200
MLMMT-83	0	562	553	546
MLMMT-84	5	29	9	8
MLMMT-85	15	12	12	6
MLMMT-86	30	11	12	4, 5, 7
MLMMT-87	60	24	10	5

Hydrated lime concentration was constant in each test at 0.5 g/L

Table 7-16. Arsenic Concentration as a Function of Hydrated Lime Content

Sample Designation	Time, min	[As], µg/L		
		Ca(OH) ₂ = 0.1 g/L	Ca(OH) ₂ = 0.5 g/L	Ca(OH) ₂ = 1.0 g/L
MLMMT-83	0	504	472	441, 502, 508
MLMMT-84	5	372	6	6
MLMMT-85	15	400	5	7
MLMMT-86	30	364	6	12
MLMMT-87	60	379	5, 10, 2	17

The P/As mole ratio was constant in each test at 10.

Table 7-17. Total Metals Concentration and TCLP Results for Product Solids from the Treatment of Mineral Hill Mine 1,300' Portal Groundwater

Sample	Description	As	Ba	Ca	Cd	Cr	Pb	Hg	Se	Ag
Concentration, mg/kg										
MLM-354A	Total Metals	728	18.5	273,000	-	7.7	16.4	-	< 15.8	< 1.2
Concentration, mg/liter										
MLM-354A	TCLP	0.15	0.06	-	< 0.005	0.03	< 0.03	< 0.0001	< 0.05	< 0.003
Reference	Max Element Conc.	5	100	-	1	5	5	0.2	1	5

Composition of the solids: 0.075% As, 0.6% P, 15.5% Ca (Determined by fluorescence analysis by Ashe Analytics, Inc.)
All TCLP tests were conducted by MSE-HKM in accordance with EPA ICP protocol.

Table 7-18. Summary of Experimental Results for Long-Term Air Sparging of Ambient Temperature Precipitated Mineral-Like Products, ASARCO Thickener Overflow Water: Time= 0

Sample	Technology Used	pH	Elemental Concentration, µg/L									
			Al	As	Cd	Cu	Pb	Mn	Hg	P	Ag	Zn
MLM-354-1	Mineral-Like Precipitation	12.2	5	4	< 5	21	< 30	< 4	0.3	30	< 3	< 13
MLM-354-2	Mineral-Like Precipitation	12.1	7	7	< 5	17	< 30	< 4	< 0.1	< 30	< 3	< 13
MLM-354-2	Mineral-Like Precipitation	12.2	2	4	< 5	18	< 30	< 4	< 0.1	40	< 3	< 13
ILM-136A-1	Ferrihydrite Adsorption	9.1	40	230	< 5	16	40	< 4	< 0.1	50	< 3	< 13
ILM-136A-1	Ferrihydrite Adsorption	9.1	20	230	< 5	16	< 30	< 4	0.1	40	< 3	< 13
ILM-136A-1	Ferrihydrite Adsorption	9.2	20	230	< 5	14	< 30	< 4	< 0.1	40	< 3	< 13

**Table 7-19. Analytical Results for ASARCO Thickener
Overflow Water Demonstration Using Low Iron Ratio**

Time (Minutes)	Arsenic Concentration (Fg/L)
0	6,300
5	100
12	200
40	100
60	100
240	300
360	600
480	500
600	200
960	400
1,440	300

**Table 7-20. Analytical Results for ASARCO Thickener
Overflow Water Demonstration Using High Iron Ratio**

Time (Minutes)	Arsenic Concentration (Fg/L)
0	6,300
5	10
12	5
40	20
60	46
240	340
360	260
480	210
600	150
960	140
1,440	201

Table 7-21. Analytical Results from Mineral Hill Mine Using Ferrihydrite Adsorption

Time (Minutes)	Arsenic Concentration (Fg/L)
0	600
1,100	40
1,590	55
1,860	52
2,550	46
3,030	73

8. Economic Analysis

One objective of this study was to perform a first order cost estimate for each of the treatment flow sheets. A “first order” cost estimate was performed using the flow sheet presented in Figures 3-1 through 3-4. The cost estimate presented here is not a detailed engineering cost analysis. It is a first order cost estimate that should be within $\pm 30\%$.

Definitions and cost estimation factors are taken primarily from “Mineral Processing Equipment Cost and Preliminary Capital Cost Estimation” (Ref. 12). Itemized equipment lists were used where possible and literature quoted cost figures were used where available. All costs were updated to the third quarter 1997 using the Marshall and Swift (M&S) Index value of 1059.6 (Ref. 13).

Major cost items have been included. The factored capital cost (FCC) totals include minor equipment, instrumentation, processing piping, auxiliary engineering, and plant size factors. An example is presented in Table 8-1.

Capital costs (using Table 8-1) and operating costs were estimated. Equipment costs were based on cost equations of the form:

$$\text{Cost}_{\text{now}} = a(\text{capacity})^b (\text{M\&S}_{\text{now}} / \text{M\&S}_{\text{then}})$$

Where, a and b are constants for a particular piece of equipment (taken from Ref. 12).

Assumptions made for the cost estimate are presented in Table 8-2.

8.1 Factored Capital Cost

An equipment list was prepared for each unit operation, and the FCC cost was estimated as

described above. The FCC was determined by using the factors as presented in Table 8-1 (selected factors for this study are highlighted).

8.2 Operating Cost

Annual operating cost estimates were established based on reagent consumption, manpower requirements, maintenance and power consumption. Reagent consumption was based on calculated mass flow. Reagent costs were taken from the Chemical Market Reporter (Ref. 14). Manpower requirements, maintenance, and power consumption were estimated using the following factors (i.e., manpower 25% FCC, maintenance 5% FCC, and power 4% FCC).

8.3 Net Present Value

The net present value (NPV) was determined by the relationship:

$$\text{NPV} = \text{FCC} + \text{USPW Operating Cost},$$

where USPW= Uniform Series Present Worth

$$\text{USPW} = [(1 + I)^n - 1 / I(1 + I)^n]$$

I= interest rate, n= number of years

Assumptions: Cost Estimate Assumptions are presented in Table 8-2.

8.4 Results

The three different technologies, mineral-like precipitation, alumina adsorption with microfiltration, and ferrihydrite adsorption were economically evaluated for a system which contained 0.5 ppb arsenic at a flow rate of 300 gallons per minute. The comparative results can be seen in Table 8-3.

Table 8-1. Factored Capital Cost Estimate Form

Item	Cost, \$
1. Purchased equipment costs	
2. Installed equipment costs	
Item 1 multiplied by 1.43	
3. Process piping	
Type plant: Percent of Item 2:	
Solid 7%-10%	
Solid-Fluid 10%-30%	
Fluid 30%-60%	
4. Instrumentation	
Amount of automatic control: Percent of Item 2:	
None 2%-5%	
Some 5%-10%	
Extensive 10%-15%	
5. Buildings and site development	
Type plant: Percent of Item 2:	
Outdoor 5%-20%	
Outdoor-Indoor 20%-60%	
Indoor 60%-100%	
6. Auxiliaries (e.g., electric power)	
Extent: Percent of Item 2:	
Existing 0%	
Minor additions 0%-5%	
Major additions 5%-25%	
New facilities 25%-100%	
7. Outside lines	
Average length: Percent of Item 2:	
Short 0%-5%	
Intermediate 5%-15%	
Long 15%-25%	
8. Total physical plant costs: Sum of Items 2+ 3+ 4+ 5+ 6+ 7	
9. Engineering and construction	
Complexity: Percent of Item 8:	
Simple 20%-35%	
Difficult 35%-60%	
10. Contingencies	
Type process: Percent of Item 8:	
Firm 20%	
Subject to change 20%-30%	
Speculative 30%-50%	
Average 30%	
11. Size factor	
Size plant: Percent of Item 8:	
Large commercial 0%-5%	
Small commercial 5%-15%	
Pilot plant 15%-35%	
12. Factored Capital Costs (FCC): Sum of Items 8+ 9+ 10+ 11	
Note: Percentages selected for this study are highlighted.	

Table 8-2. Cost Estimate Assumptions

Item	Assumptions
Site	Treatment will be conducted at a currently operating facility. Major buildings (containing sufficient space for the treatment process) are available. Analytical capabilities exist. Tailings ponding facilities are in place.
Permitting	Regulatory permits are in place.
Flow	Mineral Hill Mine water a: 300 gal/min, 330 days/yr, containing 0.5 ppb arsenic.
Solution	P/As mole ratio = 10
Cost	Interest rate= 10% Life of system= 10 years NPV= FCC + USPW Operating Cost Operating Cost factors: Reagents determined from mass flow. Manpower= 25% FCC Maintenance= 5% FCC Power= 4% FCC Not considered: depreciation, leases, salvage, tax

FCC: Factored Capital Cost
NPV: Net Present Value
USPW: Uniform Series Present Worth

Table 8-3. Economic Evaluation for Selected Technologies Treating Groundwater with 0.5 ppb Arsenic at 300 gal/min

	Mineral-Like Precipitation	Alumina Adsorption	Ferrihydrite Adsorption
Capital	\$250,000± \$75,000	\$396,000± \$118,800	\$250,000± 75,000
Operations and Maintenance per Year	\$41,080	\$130,700	\$78,904
Operations and Maintenance per 1,000 gallons treated	\$0.30 +/- 0.09	\$0.70 +/- 0.30	\$0.55 +/- 0.16

9. References

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APPENDIX A

**Arsenic Removal Project Demonstration Sampling,
Analytical, And Calibration Procedures**

1. ARSENIC REMOVAL PROJECT DEMONSTRATION SAMPLING, ANALYTICAL, AND CALIBRATION PROCEDURES

1.1 SITE SELECTION AND SAMPLING PROCEDURES

Two demonstration sites have been chosen for this project: the ASARCO Lead Smelter in East Helena, Montana and the Mineral Hill Mine located near Gardiner, Montana. Several sampling locations have also been identified at different points in the treatment trains for the three technologies being demonstrated. Selection of the correct sampling sites is necessary to ensure that the project objectives are met. Sampling sites must be selected to meet the following general criteria:

- chance of external contamination should be minimized;
- location should be representative of the entire waste stream;
- location should be as close as possible to the treatment process or the component in the treatment train being monitored to prevent further chemical changes from occurring in the waste stream; and
- sampling sites should be chosen so that the effect of each component in the treatment train can be analyzed.

1.2 SAMPLING PROCEDURES AT THE DEMONSTRATION SITE

Sampling preservative, containers, method types and references are summarized in Table A-1. The approximate sampling locations for the field demonstrations are shown in Figures A-1, A-2, and A-3. The sampling locations shall not change unless authorized by the Project Manager, with appropriate documentation that justifies the change. Tables A-4, A-5, A-6, A-7, A-8, A-9, and A-10 show sampling frequency, by position and sample type.

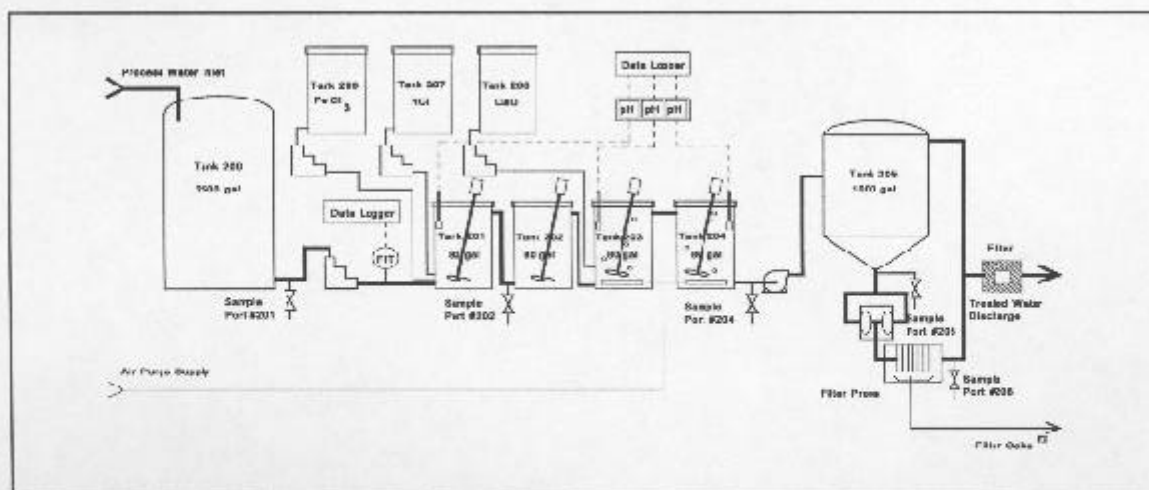


Figure A-1. Ferrihydrite process flow diagram.

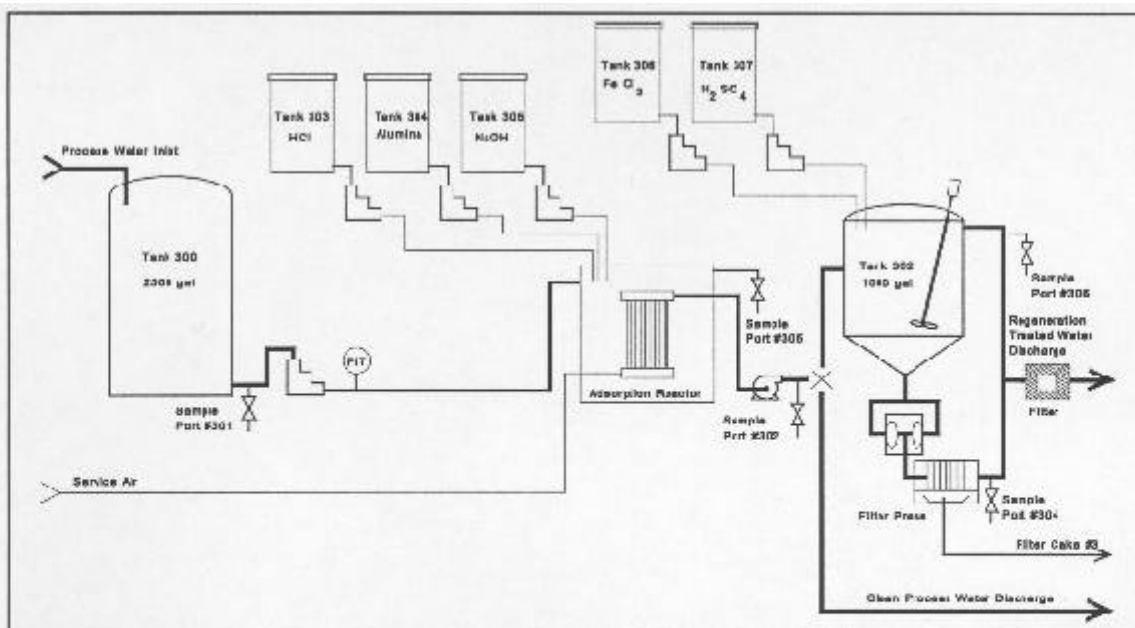


Figure A-2. Alumina absorption process flow diagram.

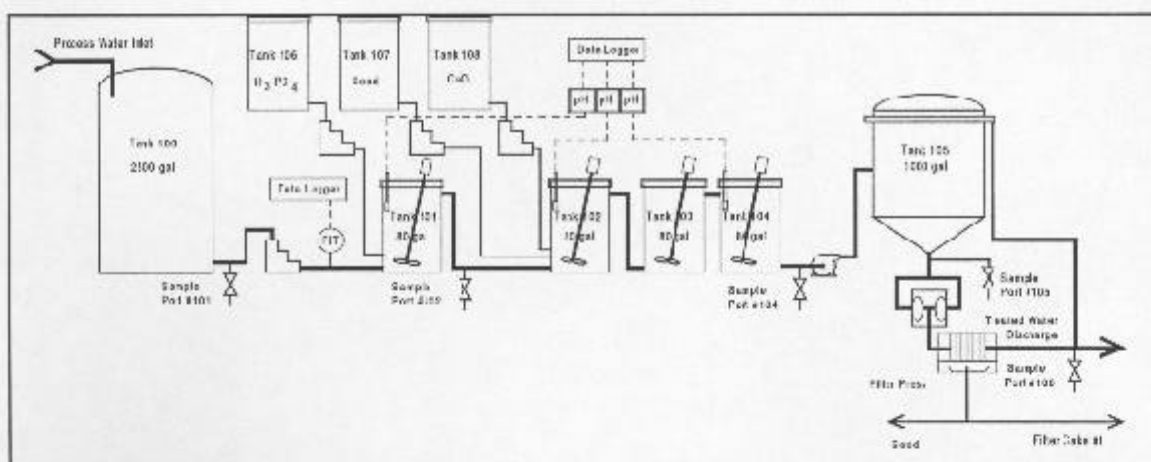


Figure A-3. Mineral-like precipitation process flow diagram.

1.2.1 Sampling Procedures

All solid and aqueous samples obtained during the demonstration will conform to the appropriate MSE Standard Operating Procedures (SOP) listed below (Table A-2) and found in Appendix C of the QAPP. All sample containers for critical measurements will be high-density polyethylene (HDPE) bottles. These bottles will only be used once (unless otherwise indicated) to prevent cross contamination of samples.

All procedures outlined in the SOP's shall be followed during sampling activities. Each aqueous sample will be taken as a single grab sample. Solid samples will be taken from homogenized solid material generated at ASARCO and the Mineral Hill Mine during each filter press operation.

Aqueous samples will be obtained at several locations in the processes depicted in Figures A-1, A-2, and A-3. The sampling tap at the sampling location will be flushed (allowed to flow briefly) before the samples are collected. Tap sampling procedures specified in EPA Method 8004 *Sampling and Analysis Methods for Hazardous Waste Combustion*, will be followed. Sample containers will be triple rinsed with small aliquots of sample, and then the sampling container will then be filled from the center of flow.

Table A-1. Preservatives, holding times, containers, method types and references.

Parameter	Matrix	Preservative	Holding Time	Sample Size & Container	Method Type	Reference
Arsenic Speciation	Aqueous	#4EC, Filter, pH#2 HCl	Analyze immediately	250-mL HDPE	Ion Exchange, Furnace AA	Ficklin Ion Exchange and Appendix C
Iron Speciation	Aqueous	#4EC, Filter, pH#2 HCl	Analyze immediately	250-mL HDPE	Colorimetric	Standard Methods 3500-Fe D, Appendix C
TSS	Aqueous	#4°C	7 days	500 mL HDPE	Gravimetric	EPA Method 160.2
Sulfate	Aqueous	#4°C	28 days	500-mL HDPE	Colorimetric	EPA Method 375.2
pH	Aqueous	None	Analyze immediately	2000-mL HDPE	pH meter	EPA (SW-846) Method 9040
Eu	Aqueous	None	Analyze immediately	100-mL HDPE	Eu meter	Equip. Manufacturer instructions
Flowrate	N/A	None	Analyze immediately	N/A	Flow meter	Manufacturer's Instructions
Total Recoverable Metals (Al, As, Cd, Cu, Fe, Pb, P, Zn by ICP)	Aqueous	#4EC, pH#2 HNO ₃	6 months	500-mL HDPE	ICP	EPA SW-846 Preparation Method 3035 ¹ /ICP Method 6010
Dissolved Metals (As by AA)	Aqueous	#4EC, Filter, pH#2 HNO ₃	6 months	500-mL HDPE	Furnace AA	EPA SW-846 Preparation/ AA Method 7060 ²
Dissolved Metals (Al, As, Cd, Cu, Fe, Pb, P, Zn by ICP)	Aqueous	#4EC, Filter, pH#2 HNO ₃	6 months	500-mL HDPE	ICP	EPA SW-846 Preparation Method 3035 ¹ /ICP Method 6010
Total Metals (Al, As, Eu, Cd, Cr, Cu, Fe, P, Pb, Se, Ag, Zn, Ca by ICP)	Solid	None	6 months	8 oz CWM	ICP	EPA SW-846 Preparation Method 3050 ¹ /ICP Method 6010
X-ray Diffraction	Solid	#4°C	6 months	20-mL HDPE	X-ray Diffraction	Appendix B
Stability Tests	Solid	None	6 months	200 g 16 oz CWM	Montana Tech Procedure	Appendix B
% Solids	Solid	None	6 months	Taken from solid sample	Drying/ Weighing	CLP SCW 3/90 Exhibit D, Part F and Appendix C
TCLP Metals	Solid	None	7 days to ext. 40 days after	At least 100 g 16 oz CWM	ICP	EPA SW-846 Extraction Method 1311/Preparation Method 3035 ¹ /ICP Method 6010

¹ Digestion method will be modified to result in a digestate concentration of 1% nitric acid, rather than 2% nitric acid.

² Matrix modifier for arsenic will be added at instrument, so the digestion procedure will be modified by bring the sample back to the original volume of 100 mL following digestion.

³ Digestion method will be modified by the addition of 10-20 mL 30% H₂O₂.

Table A-2. Summary SOPs.

SOP Number	Subject
C-1	Field Logbook/Photographs
C-2	Sample Packaging & Shipping
C-3	Field Quality Control Samples
C-4	Sample Custody

Sludge samples will be obtained from Filter Cake Locations 1, 2, and 3 following the precipitation and the separation from the treated effluent. Solid samples will be obtained from filter cakes that remain after the sludge has been dewatered by high pressure filtration. Solid samples from each filtered batch will be collected for TCLP, total metals, percent solids, and stability testing. Each solid or liquid sample that is collected will be given a unique sample ID that will distinguish it from all of the other samples collected for the project. Refer to section 4.5 for a discussion of sample labeling and sample identification numbers.

After the samples have been collected they will be preserved as shown in Table A-1. All aqueous samples shall leave no head space in the container to minimize air entrainment. Entrained air could react with species in the samples and affect the analytical results. The general procedure for obtaining aqueous samples for critical measurements from the demonstration will be as follows:

Dissolved As:

1. Obtain a clean 500 mL HDPE sampling container.
2. Open the sampling tap and flush the tap thoroughly.
3. Collect a small amount of sample in the sampling container, cap, shake to rinse, and discard the rinsate. Repeat the rinsing procedure two more times.
4. Fill container at the prescribed sampling location.
5. Obtain another clean 500-mL HDPE sampling container.
6. Using a 0.45- μ m filtering apparatus, filter at least 100 mL of water. Remove side arm and pour the filtrate directly into the sampling container. Repeat until 500 mL of sample has been filtered. Do not reuse the filter at another sampling location. Fill container completely so no headspace will remain when capped.
7. Adjust the pH of the filtered sample to <2 using nitric acid (HNO_3).
8. Cap bottle and seal per SOP for shipment to MSE Laboratory.
9. Log sample number, location, date, time, preservative, etc. per MSE SOP.
10. Repeat procedure for each duplicate or sampling location. The 500-mL HDPE container may be used for each sample if washed between samples as per SOP.
11. Store the samples in the sample refrigerator at the demonstration site at 4 °C until ready for shipment to the MSE HKM Laboratory.

The general procedure for collecting aqueous samples during the demonstration will be as follows:

1. Obtain a clean sampling container of the appropriate size.
2. Open the sampling tap and flush the tap thoroughly.
3. Collect a small amount of sample in the sampling container, cap, shake to rinse, and discard the rinsate. Repeat the rinsing procedure two more times.
4. Fill the container at the prescribed sampling tap.

5. Filter the sample if necessary. Using a 0.45 μm filter if required (see Table A-1).
6. Preserve the sample as appropriate (see Table A-1).
7. Cap the bottle, label bottle, and seal per SOP for shipment to MSE-HKM Laboratory.
8. Log sample number, location, date, time, preservative, etc. per MSE SOP.
9. Store the collected samples in the sample refrigerator at the demonstration site until ready for shipment to MSE-HKM Laboratory.

The general procedure for collecting solid samples including critical TCLP samples during the demonstration will be as follows:

1. Combine the filter cakes generated from each filtering episode and homogenize by mixing.
2. Obtain a clean 16-ounce (oz) wide mouth sampling container.
3. Scoop the solid material into the container until sufficient sample is collected (approximately 650 g). If sufficient sample is not available, collect as much of the solid material as possible and record the reason sufficient sample was not collected in the logbook and on the chain of custody.
4. Cap container and seal per SOP for shipment to MSE Laboratory.
5. Log sample number, location, date, time, preservative, etc. per MSE SOP.
6. Repeat procedure for each duplicate or sampling location.
7. Store collected samples in the sample refrigerator at the demonstration site at 4 °C until ready for shipment to MSE-HKM Laboratory.

All samples will be shipped by project personnel via ground transportation in sealed coolers containing blue ice. The samples collected from the portion of the demonstration at Mineral Hill Mine can be driven to the MSE-HKM Laboratory in a matter of hours; samples collected from the portion of the demonstration at the ASARCO lead smelting plant can be driven to the MSE-HKM Laboratory in 90 minutes. Samples that have prohibitive holding times (arsenic and iron speciation) may be shipped by an overnight carrier if project personnel are not available to transport the samples.

1.2.2 Stability Test Sampling

For the stability tests being performed at Montana Tech, pH, Eh, and temperature will be monitored in the reaction vessel. After one year, the dissolved arsenic samples will be collected using a syringe and filtered using a 0.2- μm Teflon syringe filter. After the testing period, the slurry will be filtered using suction filtration. The sampling procedure for recovering the solids for x-ray diffraction analysis and the final dissolved arsenic sample are described below:

1. Pour the slurry from the stability tests into the filtering funnel.
2. When the entire sample has been filtered, close the valve on the hood to release the suction and separate the filter flask from the filtering funnel. Set filtrate aside for dissolved arsenic sampling and analysis.
3. Remove the filter from the filtering funnel with forceps.
4. Place the filter on a clean watch glass in a 105 °C oven for at least 1 hour.
5. Remove the dried sample from the oven and place the dried sample and filter paper in the vacuum desiccator for storage, cooling, and further drying.
6. Scrape as much of the solid material as possible from the filter into a tared HDPE container.
7. Weigh the sample and record the weight of the sample and container in the project logbook.

8. Label the samples with information summarized in Section 4.1.3 of the QAPP.
9. Store the sample in the refrigerator in the Montana Tech Metallurgy Department until ready for x ray diffraction analysis.

Aqueous samples will be collected as syringe filtrates from either the reaction vessel after one year or the filtering flask after the 2 year aging period. Contents of the reaction vessel will be homogenized by the air that is continuously sparging in. Contents of the filtering flask will be manually homogenized by shaking prior to sampling. Syringe filter sampling is described below:

1. Obtain a clean 20-mL sampling vial, syringe, plunger, and 0.2- μ m Teflon membrane syringe filter.
2. Process approximately 20 mL of distilled/deionized (DI/DS) water through the syringe and syringe filter.
3. Homogenize the sample.
4. Process approximately 5 mL of sample through the syringe filter apparatus into the sample vial.
5. Cap the sample vial and shake to rinse the vial with the sample. Open the sample container and discard rinsate.
6. Homogenize the sample.
7. Process enough homogenized sample through the syringe filter to fill the sample vial, leaving no headspace. Preserve the sample if necessary. Label the sample as outlined in Section 4.1.3 of the QAPP.
8. Store the sample in the refrigerator in the Metallurgy Department at Montana Tech until ready for shipment to MSE-HKM Laboratory in a sealed cooler.

1.2.3 Sample Labeling

All samples will be clearly labeled following sample collection. The information recorded on the label will include:

- project name;
- demonstration site (ASARCO, Mineral Hill Mine, Montana Tech);
- sample type and analysis to be performed;
- sample description (i.e., influent, effluent);
- date and time sample was collected;
- sampler's initials;
- sample identification number;
- preservative and/or sample preparation techniques (i.e., preservatives added, filtered); and
- other remarks or special instructions.

To ensure that each sample is assigned a unique sample identification number, the following information will be provided about each sample:

- process identification [mineral-like precipitation (ML), ferrihydrite (IC), or alumina adsorption w/microfiltration (AL), stability tests (S)];
- demonstration site [ASARCO (A), Mineral Hill (M), Montana Tech]; and
- sample number (samples will be numbered consecutively from 101 for mineral-like precipitation, from 201 for ferrihydrite, from 301 for alumina adsorption w/microfiltration, and from 401 for stability tests).

For example, the first sample collected from the mineral-like precipitation process during the demonstration at the ASARCO East Helena lead smelter would be assigned the following sample identification number: MLA-101. Each sample following this collection would be assigned the next consecutive number (i.e., MLA-102, MLA-103, etc.)

2. ANALYTICAL PROCEDURES AND CALIBRATION

The analytical procedures used during the project are summarized in Table A-3. A brief discussion of the procedures used for each analysis are discussed below.

Table A-3. Project Schedule and Milestones for MWTP, Activity III, Project 9.

Milestone	Date
Work Plan	February 28, 1997
Site Access Agreements	May 30, 1997
NEPA Documentation	May 16, 1997
Vendor Subcontracts	June 30, 1997
Preliminary Design	March 21, 1997
Definitive Design	June 30, 1997
Project Specific Quality Assurance Project Plan	June 30, 1997
Fabrication	July 15, 1997
Construction Subcontract	June 20, 1997
Field Installation	July 18, 1997
Finalize Test Plan	July 4, 1997
Field Demonstration Completion	October 31, 1997
Draft Final Project Report	January 30, 1998
Stability Testing	October 31, 1999
Revision to Final Report	November 30, 1999

2.1 DISSOLVED ARSENIC (AA)

A Varian-Spectra AA 400 Graphite Furnace AA with Zeeman background correction will be used to analyze the As speciation vials as well as the dissolved arsenic concentration in the effluent at the MSE-HKM Laboratory. The furnace AA will be calibrated according to procedures outlined in EPA SW-846 Method 7060.

2.2 DISSOLVED, TOTAL RECOVERABLE, AND TOXICITY CHARACTERISTIC LEACHING PROCEDURE METALS ANALYSIS BY INDUCTIVELY COUPLED PLASMA EMISSION SPECTROMETER

Dissolved and total recoverable metals will be determined using SW-846 Method 6010A on an ARL 3560 Inductively Coupled Plasma Emission Spectrometer (ICP). The samples will be prepared for ICP analysis as outlined in SW-846 Method 3005A. The digestion procedure for total recoverable metals

will be modified to result in a matrix of 1% rather than 2% nitric acid.

The ICP will be calibrated according to the procedures outlined in SW-846 Method 6010 and the equipment manufacturer's instructions. Calibration will consist of the following procedures and items:

- mixed calibration standards;
- calibration blanks and reagent blanks;
- independent check standard;
- interference check solutions; and
- quality control samples.

2.2.1 Initial Calibration Verification

Calibration of the instrument will be verified using a mixed calibration standard from a different source and at different concentrations than the calibration standards. The concentrations of the analytes will be within the calibration range of the instrument and the analytes must be between 90%–110% of the true value or the calibration of the instrument will be repeated.

2.2.2 Continuing Calibration Verification

The calibration of the instrument will be continuously monitored by analyzing a CCV every 10 samples or every two hours, whichever is more frequent. The limit of acceptance for this standard is also 90%–110% of the true value of the analyte concentration. Should the calibration be out of compliance, the instrument will be recalibrated and the samples analyzed since the last compliant CCV will be reanalyzed.

2.2.3 Initial and Continuing Calibration Blanks

An ICB will be analyzed immediately after the ICV, and a CCB will be analyzed following the CCV. If the absolute value of the concentration exceeds the instrument detection limit, the instrument will be recalibrated and any samples since the last compliant CCB will be reanalyzed.

2.2.4 Interference Check Samples A and B

To verify interelement and background correction factors, an ICSA and ICSAB will be analyzed at the beginning and end of each analysis run or at a minimum of twice per 8-hour working shift. Results should fall within the control limits of 20% of the true value. If the results fall outside the specified control limits, the analysis will be terminated, the problem corrected, the ICP recalibrated, and the analytical samples reanalyzed since the last compliant interference check sample will be reanalyzed.

2.3 pH

Although process pH measurements will be made through installed probes, some pH measurements will be done manually using a hand-held probe. A pH meter with automatic temperature compensation

capable of measuring pH at the demonstration site to 0.1 pH units will be used for this project. The pH probe will be calibrated daily using two fresh buffer solutions that bracket the expected pH. The meter will be calibrated before analysis begins, and calibration will be verified following the initial calibration and every 10 samples using a third buffer solution within the calibration range. If the third buffer solution differs from the true value of the buffer by more than 0.2 pH units, the meter will be recalibrated, and all samples analyzed since the last compliant calibration verification will be reanalyzed.

2.4 E_H

An Orion E_H meter with a silver/silver chloride reference electrode will be used to determine the E_H at the demonstration site. The electrode will be calibrated using Zocbell's solution of known E_H. The measured Zocbell E_H must be within 20% of the known solution value or the probe will be subjected to cleaning and other required maintenance before recalibration.

2.5 ARSENIC SPECIATION

The total dissolved As, As⁺³, and As⁻⁵ in influent and effluent samples from the process trains will be determined using furnace AA, following the speciation using the Ion Exchange Ficklin Method (Ref. 1). The SOP that the MSE-HKM laboratory will be using is contained in Appendix C. The procedure involves passing 5 mL of the filtered, acidified sample through an ion exchange column packed with Donwex 1 x 8 anion exchange resin in 100-200 mesh size. The As⁻⁵ adheres to the acetate form of the ion exchange resin, while the As⁺³ passes through the column. To ensure the recovery of all of the As⁺³, the column is eluted with three separate 5-mL portion of deionized water. The original 5-mL sample and each elution will be collected in separate vials numbered 1 through 4. These vials contain the As⁺³. The column is then eluted with three separate 5-mL portions of 0.12M of Hydrochloric Acid (HCl). The pH change and the subsequent ion exchange cause the As⁻⁵ to pass through the column. The final three vials of sample collected contain the As⁻⁵. All of the speciation vials, as well as an unspicated total dissolved arsenic sample, will be analyzed by furnace AA to determine the concentrations of total dissolved As, As⁻³, and As⁻⁵. The concentrations of the species added together divided by the measured total dissolved concentrations of arsenic will be calculated to determine if the recovery is acceptable (80%-120% recovery). If the recovery is not acceptable, the analyses will be repeated. This is a specific calculation for arsenic speciation analysis and should not be confused with the spike recovery calculation. The percent recovery of arsenic calculation will be determined using the calculation presented in Section 9 of the QAPP.

2.6 IRON SPECIATION

The concentration of dissolved iron will be determined by ICP at the MSE-HKM Laboratory. The concentration of ferrous iron will be determined using the colorimetric Standard Method 3500-Fe D and phenanthroline as the color developer. The spectrophotometer will be calibrated with a blank and at least three standards. The concentration of ferric iron will be calculated by subtracting the concentration of ferrous iron from the dissolved iron concentration determined by ICP. The MSE-HKM Laboratory SOP for this analysis is contained in Appendix C of the QAPP.

2.7 TOTAL SUSPENDED SOLIDS

Total suspended solids (TSS) will be determined at the MSE-HKM Laboratory according to EPA Method 160.2. A homogenized sample will be filtered through a glass fiber filter and the residue retained by the filter is dried to a constant weight in a 103-105 °C oven. A duplicate and a blank sample will be analyzed every 10 samples. Calibration of scales and oven temperature are verified on a daily basis and recorded in laboratory notebooks.

2.8 SULFATE

A Perstorp Flow Solution Auto Analyzer will be used to make sulfate determinations at the MSE-HKM Laboratory according to EPA Method 375.2. The auto analyzer is calibrated using at least five calibration standards between 10 and 200 mg/L. The calibration curve is then verified by analyzing an initial calibration verification standard, which is from a different source than the calibration standards. Calibration is continuously verified by analyzing a continuing calibration standard every 10 samples. Initial and continuing calibration blanks are also analyzed to verify that no significant contamination will occur at the instrument from instrument carryover from the calibration standards.

2.9 TOXICITY CHARACTERISTIC LEACHING PROCEDURE

Solid materials will be subjected to the TCLP procedure outlined in SW-846 Method 1311 at the MSE-HKM Laboratory. If sufficient sample is not available from filter cake samples, the TCLP procedure will be modified according to the weight of the solids submitted for analysis. The amount of extraction fluid added to the sample is determined by the weight of the sample and will be adjusted according to the sample weight. All reagent additions will be adjusted accordingly. The resulting extraction fluids from the TCLP will be digested according to procedures outlined in SW-846 Method 3005A for total recoverable metals. In addition to the reagents listed in the method 20 mL of 30% H₂O₂ will be added to the samples to help degrade the acetic acid. Digested samples will be analyzed by ICP. The ICP will be calibrated as discussed in Section 4.1 of the QAPP.

2.10 TOTAL METALS

The solid samples will be characterized for total metals by ICP SW-846 Method 6010A at the MSE-HKM Laboratory. Samples will be digested according to SW-846 Method 3050A. The ICP will be calibrated as discussed in Section 4.1 of the QAPP before sample digestates are analyzed.

2.11 PERCENT SOLIDS

The percent solids of each solid sample will be determined at the MSE-HKM Laboratory using the method outlined in Exhibit D, Part F of the Contract Laboratory Program Statement of Work, Document Number IIm03.0. A copy of this method is contained in Appendix C of the QAPP. The percent solids data will be used to report the metals on a dry weight basis.

2.12 STABILITY TESTS

In order to determine if the filter cakes generated by mineral-like precipitation and ferrihydrite are stable to tailings pond environment using the Montana Tech Procedure, a long term leach test developed during MWTP Activity 4, Project 5. The stability testing will be performed at the Metallurgy Department at Montana Tech. The procedure for each stability test is presented in Appendix B. The tests will be performed in triplicate on the filtercake samples generated during the project.

2.13 X-RAY DIFFRACTION

X-ray diffraction analysis will be performed using a Phillips 3100 X-ray Generator. The instrument will be calibrated using a National Institute of Standards and Technology standard reference material. If the average delta 2-theta is greater than 0.1, the instrument will be recalibrated. Sample preparation procedures are discussed in the SOP contained in Appendix B of the QAPP.

2.14 CALIBRATION PROCEDURES FOR FIELD PROCESS INSTRUMENTS

All instruments used to measure field process variables will be calibrated using National Institute of Standards and Testing (NIST) traceable test equipment furnished by the Western Environmental Technology Office (WETO) in the MSE Technology Applications Instrumentation and Control Laboratory. The test equipment used during the calibration procedures are verified on a routine basis at Instrument Repair Laboratory in Broomfield, Colorado. This is a certified NIST secondary standards laboratory. Calibration procedures for critical and noncritical process field measurements are summarized in Table 18 of the QAPP. Calibration procedures will be performed prior to project start-up and after the project has been completed.

Table A-4. Sample port/location descriptions and sample matrix at each location for the mineral-like precipitation skid and the ASARCO ferrihydrite process.

Sample Port/Sample	Description	Matrix
101	Process influent for the mineral-like precipitation system	aqueous
102	Process water after H_3PO_4 addition for the mineral-like precipitation system	aqueous
104	Process water after seed and CaO addition for the mineral-like precipitation system	aqueous
106	Treated water discharge for the mineral-like precipitation system	aqueous
Filter Cake #1	Sludge product from the mineral-like precipitation system	solid
FIT	Flow totalizer in the mineral-like precipitation system	aqueous
pH	Tank 101, 102, 104 pH monitors in the mineral-like precipitation system	aqueous
401	Process influent for the ASARCO ferrihydrite process	aqueous
406	Treated water discharge for the ASARCO ferrihydrite process	aqueous
Filter Cake #4	Sludge product for the ASARCO ferrihydrite process	solid

Table A-5. Noncritical and critical measurements and frequency for the demonstration of the mineral-like precipitation process and the ferrihydrite process at the East Helena ASARCO lead smelting plant

Measurement	Matrix	Classification	Sample Frequency	Sample Location	Total Number of Samples
pH	aqueous	noncritical	Initially, every hour for 8 hours, then every 4 hours	pH probes in tank 101, tank 102, and tank 104	69
pH	aqueous	noncritical	Before discharge	106	3
Eu	aqueous	noncritical	Initially, every hour for 8 hours, then every 4 hours	102 and 104	46
Total flow	aqueous	noncritical	Initially, every hour for 8 hours, then every 4 hours	FIT (total flow indicator)	23
As speciation	aqueous	noncritical	Every 24 hours of operation	101 and 106	6
Iron speciation	aqueous	noncritical	Every 24 hours of operation	101 and 106	6
Total recoverable metals (As, Cd, Cu, Pb, Fe, P, Zn)	aqueous	noncritical	Every 24 hours of operation	101, 102, 104, 106	12
Dissolved metals (Cd, Cu, Fe, Pb, Zn)	aqueous	noncritical	Every 24 hours of operation	101, 102, 104, 106	12
Dissolved metals (As, P)	aqueous	noncritical	Initially, every 12 hours of operation	102 and 104	14
Total metals (As, Ba, Cd, Cr, Cu, Fe, P, Pb, Se, Ag, Zn, Ca)	solid	noncritical	Each sludge sample	Filter Cake #1	3
% solids	solid	noncritical	Each sludge sample	Filter Cake #1	3
TCLP (Ba, Cd, Cr, Pb, Hg, Se, Ag)	solid	noncritical	Each sludge sample	Filter Cake #1	3
Stability tests	solid	noncritical	Each sludge sample	Filter cake #1	3
TCLP (As)	solid	critical	Each sludge sample	Filter cake #1, ASARCO sludge	3
Dissolved metals (As)	aqueous	critical	Initially, every 8 hours of operation	101 and 106	18

Note: Sample collection will begin after the one system volume has been processed.

Table A-6. Noncritical and critical measurements for the ASARCO ferrihydrite process.

Measurement	Matrix	Classification	Frequency	Location	Total Number of Samples
pH	aqueous	noncritical	initial	401 and 406	2
Eu	aqueous	noncritical	initial	401	1
Flow rate	aqueous	noncritical	initial	401	1
As speciation	aqueous	noncritical	initial	406	1
Total recoverable metals (As, Cd, Cu, Pb, Fe, Zn)	aqueous	noncritical	initial	401	1
Dissolved metals (Cd, Cu, Fe, Pb, Zn)	aqueous	noncritical	initial	401	1
TCLP (Ba, Cd, Cr, Pb, Hg, Se, Ag)	solid	noncritical	once	Filter cake #4	1
TCLP (As)	solid	critical	once	Filter cake #4	1
Dissolved metals (As)	aqueous	critical	Every day the mineral-like precipitation process is being demonstrated	401 and 406	6

Note: Initial samples will be collected from the ASARCO ferrihydrite process just prior to the startup of the mineral-like precipitation process demonstration.

Table A-7. Noncritical and critical measurements for the mineral-like precipitation process demonstration at the Mineral Hill Mine (17-day test with 1,300-foot-level portal discharge water).

Measurement	Matrix	Classification	Sample Frequency	Sample Location	Total Number of Samples
pH	aqueous	noncritical	Initially every hour for 8 hours, then every 4 hours	pH probes in tank 101, tank 102, and tank 104	144
pH	aqueous	noncritical	Before discharge	106	11
En	aqueous	noncritical	Initially every hour for 8 hours, then every 4 hours	102 and 104	96
Total flow	aqueous	noncritical	Initially every hour for 8 hours, then every 4 hours	FIT (total flow indicator)	48
As speciation	aqueous	noncritical	initial	101	1
Total recoverable metals (As, Cd, Cu, Pb, Fe, P, Zn)	aqueous	noncritical	Every 48 hours of operation	101, 102, 104, 106	16
Dissolved metals (Cd, Cu, Fe, Pb, Zn)	aqueous	noncritical	Initially every 48 hours of operation	101, 102, 104, 106	16
Dissolved metals (As, P)	aqueous	noncritical	Every 24 hours of operation	102 and 104	16
Total metals (As, Ba, Cd, Cr, Cu, Fe, F, Pb, Se, Ag, Zn, Cs)	solid	noncritical	Each sludge sample	Filter cake #1	1
% Solids	solid	noncritical	Each sludge sample	Filter cake #1	1
TCLP (Ba, Cd, Cr, Pb, Hg, Se, Ag)	solid	noncritical	Each sludge sample	Filter cake #1	1
Stability tests	solid	noncritical	Each sludge sample	Filter cake #1	1
TCLP (As)	solid	critical	Each sludge sample	Filter cake #1	1
Dissolved metals (As)	aqueous	critical	Initially every 8 hours of operation	101 and 106	44

Note: Initial sample collection will begin after the one system volume has been processed.

Table A-8. Noncritical and critical measurements for the mineral-like precipitation process with concentrated arsenic brine from the alumina adsorption with microfiltration process.

Measurement	Matrix	Classification	Frequency	Location	Total Number of Samples
pH	aqueous	noncritical	Initial, every 4 hours	pH probes in tank 101, tank 102, and tank 103	12
pH	aqueous	noncritical	Before discharge	106	1
En	aqueous	noncritical	Initial, every 4 hours	102 and 104	8
As Speciation	aqueous	noncritical	Initial	101	1
Total Recoverable Metals (Al, As, Cd, Cu, Pb, Fe, P, Zn)	aqueous	noncritical	Initial	101 and 106	2
Dissolved Metals (Al, Cd, Cu, Pb, Fe, P, Zn)	aqueous	noncritical	Initial	101 and 106	2
Dissolved Metals (As)	aqueous	critical	Initial, every 4 hours	101 and 106	6

Note: Initial Samples will be collected after one system volume has been processed.

Table A-9. Sample port/location descriptions and sample matrix at each location for the ZENON alumina adsorption with microfiltration process.

Sample Port/Sample Location	Description	Matrix
301	Process water influent	aqueous
302	Adsorption reactor effluent	aqueous
304	Treated water discharge	aqueous
305	Adsorption reactor tank	aqueous
306	Settling tank	aqueous
Filter cake #3	Sludge product	solid
FIT	Flow totalizer	aqueous

Table A-10. Noncritical and critical measurements for the alumina adsorption with microfiltration demonstration at the Mineral Hill Mine (1 test with 1,300-foot-level portal water, and tests with effluents from other processes, if necessary).

Measurement	Matrix	Classification	Sample Frequency	Sample Location	Total Number of Samples
pH	aqueous	noncritical	Initially, every 12 hours	301, 302, 303, and 304	52
pH	aqueous	noncritical	Before discharge	304	6
Total flow	aqueous	noncritical	Initially, every 12 hours	FIT (Total flow indicator)	13
Total flow	aqueous	noncritical	initial, every 4 hours	FIT	4
Total suspended solids (TSS)	aqueous	noncritical	Initially, every 24 hours of operation	301, 302, 305, and 306	28
Sulfate	aqueous	noncritical	Initially, every 24 hours of operation	301 and 302	8
Total recoverable metals (Al, As, Cd, Cu, Pb, Fe, Zn)	aqueous	noncritical	Initially, every 24 hours of operation	301, 302, and 304	8
Dissolved metals (Al, Cd, Cu, Fe, Pb, Zn)	aqueous	noncritical	Initially, every 24 hours of operation	301, 302, and 304	8
Dissolved metals (As)	aqueous	critical	Initially, every 12 hours of operation	301 and 304	26

Note: Initial samples will be collected after one system volume has been processed. Total number of samples does not include samples from processing effluents from the other processes since it is unknown at this time if further processing of the effluents will be necessary.

Table A-11. Sample port/location descriptions and sample matrix at each location for the ferrihydrite process at the Mineral Hill Mine.

Sample Port/Sample Location	Description	Matrix
201	Process influent	aqueous
202	Process influent after FeCl ₃ addition	aqueous
204	Process influent with HCl and CaO addition	aqueous
206	Treated water discharge	aqueous
Filter cake #2	Sludge product	solid
FIT	Flow totalizer	aqueous
pH	Tank 201, 203, and 204 pH monitors	aqueous

Table A-12. Noncritical and critical measurements for the Mineral Hill demonstration of the ferrihydrite process (day test with 1,300-foot level portal discharge water).

Measurement	Matrix	Classification	Sample Frequency	Sample Location	Total Number of Samples
pH	aqueous	noncritical	Initially, every hour for 8 hours, then every 4 hours	pH probes in tank 201, tank 203, and tank 204	126
pH	aqueous	noncritical	Before discharge	206	9
E _H	aqueous	noncritical	Initially, every hour for 8 hours, then every 4 hours	202 and 204	84
Total flow	aqueous	noncritical	Initially, every hour for 8 hours, then every 4 hours	FIT (total flow indicator)	42
Total recoverable metals (As, Cd, Cu, Pb, Fe, Zn)	aqueous	noncritical	Every 48 hours of operation	201, 202, 204, 206	12
Dissolved metals (Cd, Cu, Pb, Zn)	aqueous	noncritical	Every 48 hours of operation	201, 202, 204, 206	12
Dissolved metals (As, Fe)	aqueous	noncritical	Initially, every 24 hours of operation	202 and 204	14
Total metals (As, Ba, Cd, Cr, Cu, Fe, Pb, Se, Ag, Zn, Ca)	solid	noncritical	Each sludge sample	Filter cake #2	1
% solids	solid	noncritical	Each sludge sample	Filter cake #2	1
TCLP (Ba, Cd, Cr, Pb, Hg, Se, Ag)	solid	noncritical	Each sludge sample	Filter cake #2	1
Stability tests	solid	noncritical	Each sludge sample	Filter cake #2	1
TCLP (As)	solid	critical	Each sludge sample	Filter cake #2	1
Dissolved metals (As)	aqueous	critical	Initially, every 8 hours of operation	201 and 206	38

Note: Sample collection will begin after the one system volume has been processed.

Table A-13. Noncritical and critical measurements for the ferrihydrite process using concentrated arsenic brine from the alumina adsorption with microfiltration process.

Measurement	Matrix	Classification	Frequency	Location	Total Number of Samples
pH	aqueous	noncritical	Initial, every 4 hours	pH probes in tank 201, tank 203, and tank 204	12
pH	aqueous	noncritical	Before discharge	206	1
E _H	aqueous	noncritical	Initial, every 4 hours	202 and 204	3
Total recoverable metals (Al, As, Cd, Cu, Pb, Fe, P, Zn)	aqueous	noncritical	Initial	206	1
Dissolved metals (Al, Cd, Cu, Pb, Fe, P, Zn)	aqueous	noncritical	initial	206	1
Dissolved metals (As)	aqueous	critical	initial, every 4 hours	201 and 206	6

Note: Initial Samples will be collected after one system volume has been processed.

Table A-14. Field quality control sampling for each process demonstration.

Analysis	Field Duplicates	Field Blanks
Dissolved Arsenic	1 ¹	1 ¹
TCLP	1 ²	N/A

¹ Field QC samples are to be taken at the initial and final sampling events technology demonstration. The initial set of field QC samples will be taken from influent locations (101, 201, and 301), and the final set of field QC samples will be taken from the effluent locations (106, 206, and 304).² A Field duplicate will be taken at each site for each technology demonstration from resulting filter cakes

Table A-15. Sampling frequency for the stability tests.

Measurement	Matrix	Classification	Frequency	Sample Location	Total Number of Samples
Sample weight	solid	noncritical	Before and after test	Sample before test, vacuum filter after test	48
Dissolved As	aqueous	noncritical	Every year	Syringe filtrate	24
pH	slurry	noncritical	Every year	Reaction vessel	24
En	slurry	noncritical	Every year	Reaction vessel	24
Temperature	slurry	noncritical	Every year	Reaction vessel	24
X-ray diffraction	solid	noncritical	After test	Vacuum filter	12

Table A-16. Total number of samples.

Analysis	Primary Samples Site Demos	Primary Samples Stability Tests	Field Duplicates	Field Blanks	Project Total
pH	447	24	n/a	n/a	471
En	243	24	n/a	n/a	267
Total flow	134	n/a	n/a	n/a	134
TSS	28	n/a	n/a	n/a	28
Sulfate	8	n/a	n/a	n/a	8
Arsenic speciation	9	n/a	n/a	n/a	9
Iron speciation	6	n/a	n/a	n/a	6
X-ray diffraction	n/a	12	n/a	n/a	12
Total recoverable metals (aqueous)	52	n/a	n/a	n/a	52
Dissolved metals	101	n/a	n/a	n/a	101
Total metals (solid)	5	n/a	n/a	n/a	5
TCLP	6	n/a	6	n/a	12
Dissolved arsenic	144	24	12	12	192
% solids	5	n/a	n/a	n/a	5
Total number of samples	1,188	84	18	12	1,302

2.14 REFERENCES

1. Ficklin, Walter H., "Separation of Arsenic(III) and Arsenic(V) in Ground Water by Ion Exchange," *Talanta Vol 30*, No. 5, 1983, pp 371-373.

APPENDIX B

Test Data

MINERAL-LIKE PRECIPITATION TEST DATA

MINERAL-LIKE PRECIPITATION TEST DATA																						
Field #		Sample ID	Date Sampled	Time Sampled	Sample Type	Al (mg/L)	As (mg/L)	Ba (mg/L)	Ca (mg/L)	Cd (mg/L)	Co (mg/L)	Cu (mg/L)	Fe (mg/L)	Mn (mg/L)	Pb (mg/L)	Se (mg/L)	Si (mg/L)	T (mg/L)	Zn (mg/L)	Chloride (mg/L)	Sulfate (mg/L)	As (mg/L)
Average Speciation Results																						
U		U-001-01	101	07/24/07	12:15 PM	SPEC																
U-001-01		102	07/24/07	12:20 PM	DSS		3033.763							1237.00	1000.302							3380.065
U-001-02		104	07/24/07	12:23 PM	DSS		0.000	0.0072					0.073	00.758								
U-001-03		105	07/24/07	12:25 PM	DSS		0.752						1.168	35.962								
U-001-04		101	07/24/07	12:25 PM	DSS		3151.072							1754.563	851.140					1540.81	535.1	
U-001-05		101	07/24/07	12:27 PM	DSS																	
U-001-06		105	07/24/07	12:27 PM	DSS		0.007	0.00380					0.15	34.233								
U-001-07		101	07/24/07	07:30 PM	DSS		3333.902							25.31								
U-001-08		105	07/24/07	07:30 PM	DSS		0.00383	0.0032														
MHA-109		109	07/24/07	07:30 PM	DSS																	
MHA-110		109	07/24/07	07:30 PM	DSS		3434.715	0.071						1709.83								
MHA-111		109	07/24/07	07:30 PM	DSS		0.030							14.363								
MHA-112		109	07/24/07	07:30 PM	DSS		0.051	0.00688						11.06								
MHA-113		109	07/24/07	07:30 PM	DSS		0.053	0.0203						31.462								
MHA-114		109	07/24/07	07:30 PM	DSS		0.016414															
MHA-115		109	07/24/07	07:30 PM	DSS		0.0275	0.00395														
MHA-116		109	07/24/07	07:30 PM	DSS		0.01921	0.00232														
MHA-117		109	07/24/07	07:30 PM	DSS																	
MHA-118		109	07/24/07	07:30 PM	DSS		0.00774															
MHA-119		109	07/24/07	07:30 PM	DSS		3376.826	0.00774														
MHA-120		109	07/24/07	07:30 PM	DSS		225.867	194.47	1.13	02.14	24.206	1701.009	00.5	27.303	113.387	00.111	70.342					
MHA-121		109	07/24/07	07:30 PM	DSS		475.474	195.013	1.264	25.634	4.291	1796.348	48.105	27.33	59.266	69.291						
MHA-122		109	07/24/07	07:30 PM	DSS		0.016	176.339	0.006	0.021	0.008	8.001	1									
MHA-123		109	07/24/07	07:30 PM	DSS		0.007	6.144														
MHA-124		109	07/24/07	07:30 PM	DSS		0.00079	0.00010	0.0380	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MHA-125		109	07/24/07	07:30 PM	DSS		0.00079	0.00010	0.0380	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MHA-126		109	07/24/07	07:30 PM	DSS		0.00079	0.00010	0.0380	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MHA-127		109	07/24/07	07:30 PM	DSS		0.00079	0.00010	0.0380	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MHA-128		109	07/24/07	07:30 PM	DSS		0.00079	0.00010	0.0380	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MHA-129		109	07/24/07	07:30 PM	DSS		0.00079	0.00010	0.0380	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MHA-130		109	07/24/07	07:30 PM	DSS		0.00079	0.00010	0.0380	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MHA-131		109	07/24/07	07:30 PM	DSS		0.00079	0.00010	0.0380	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MHA-132		109	07/24/07	07:30 PM	DSS		0.00079	0.00010	0.0380	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MHA-133		109	07/24/07	07:30 PM	DSS		0.00079	0.00010	0.0380	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MHA-134		109	07/24/07	07:30 PM	DSS		0.00079	0.00010	0.0380	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MHA-135		109	07/24/07	07:30 PM	DSS		0.00079	0.00010	0.0380	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MHA-136		109	07/24/07	07:30 PM	DSS		0.00079	0.00010	0.0380	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MHA-137		109	07/24/07	07:30 PM	DSS		0.00079	0.00010	0.0380	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MHA-138		109	07/24/07	07:30 PM	DSS		0.00079	0.00010	0.0380	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MHA-139		109	07/24/07	07:30 PM	DSS		0.00079	0.00010	0.0380	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MHA-140		109	07/24/07	07:30 PM	DSS		0.00079	0.00010	0.0380	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MHA-141		109	07/24/07	07:30 PM	DSS		0.00079	0.00010	0.0380	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MHA-142		109	07/24/07	07:30 PM	DSS		0.00079	0.00010	0.0380	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MHA-143		109	07/24/07	07:30 PM	DSS		0.00079	0.00010	0.0380	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MHA-144		109	07/24/07	07:30 PM	DSS		0.00079	0.00010	0.0380	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MHA-145		109	07/24/07	07:30 PM	DSS		0.00079	0.00010	0.0380	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MHA-146		109	07/24/07	07:30 PM	DSS		0.00079	0.00010	0.0380	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MHA-147		109	07/24/07	07:30 PM	DSS		0.00079	0.00010	0.0380	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MHA-148		109	07/24/07	07:30 PM	DSS		0.00079	0.00010	0.0380	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MHA-149		109	07/24/07	07:30 PM	DSS		0.00079	0.00010	0.0380	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MHA-150		109	07/24/07	07:30 PM	DSS		0.00079	0.00010	0.0380	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MHA-151		109	07/24/07	07:30 PM	DSS		0.00079	0.00010	0.0380	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MHA-152		109	07/24/07	07:30 PM	DSS		0.00079	0.00010	0.0380	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MHA-153		109	07/24/07	07:30 PM	DSS		0.00079	0.00010	0.0380	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MHA-154		109	07/24/07	07:30 PM	DSS		0.00079	0.00010	0.0380	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MHA-155		109	07/24/07																			

[illegible]

M.A-210		100	06/04/97	12:00 AM	DISS	As (CP)	As (mg/L)	As (ug/L)	Fe (mg/L)	Pb (mg/L)	Mn (mg/L)	Se (mg/L)	Ti (mg/L)	Zn (mg/L)	Chloride (mg/L)	Sulfate (mg/L)	As (ug/L)	As (ug)
FIELD ID	SAMPLE ID	DATE SAMPLED	TIME SAMPLED	SAMPLE TYPE	AL (mg/L)	AS (CP)	AS (mg/L)	AS (ug/L)	Fe (mg/L)	Pb (mg/L)	Mn (mg/L)	Se (mg/L)	Ti (mg/L)	Zn (mg/L)	Chloride (mg/L)	Sulfate (mg/L)	As (ug/L)	As (ug)
M.A-210A	100C	06/04/97	12:00 AM	DISS	0.031	0.00453	<0.001	0.001	0.045	<0.002	0.011	0.004	0.004	0.004	0.004	0.004	0.004	0.004
M.A-211	101	06/04/97	12:00 AM	DISS	0.031	0.00453	<0.001	0.001	0.045	<0.002	0.011	0.004	0.004	0.004	0.004	0.004	0.004	0.004
M.A-212	102	06/04/97	12:00 AM	DISS	0.031	0.00453	<0.001	0.001	0.045	<0.002	0.011	0.004	0.004	0.004	0.004	0.004	0.004	0.004
M.A-213	103	06/04/97	12:00 AM	DISS	0.031	0.00453	<0.001	0.001	0.045	<0.002	0.011	0.004	0.004	0.004	0.004	0.004	0.004	0.004
M.A-214	104	06/04/97	12:00 AM	DISS	0.031	0.00453	<0.001	0.001	0.045	<0.002	0.011	0.004	0.004	0.004	0.004	0.004	0.004	0.004
M.A-215	105	06/04/97	12:00 AM	DISS	0.031	0.00453	<0.001	0.001	0.045	<0.002	0.011	0.004	0.004	0.004	0.004	0.004	0.004	0.004
M.A-216	106	06/04/97	12:00 AM	DISS	0.031	0.00453	<0.001	0.001	0.045	<0.002	0.011	0.004	0.004	0.004	0.004	0.004	0.004	0.004
M.A-216A	106A	06/04/97	12:00 AM	DISS	0.031	0.00453	<0.001	0.001	0.045	<0.002	0.011	0.004	0.004	0.004	0.004	0.004	0.004	0.004
M.A-216B	106B	06/04/97	12:00 AM	DISS	0.031	0.00453	<0.001	0.001	0.045	<0.002	0.011	0.004	0.004	0.004	0.004	0.004	0.004	0.004
M.A-216C	106C	06/04/97	12:00 AM	DISS	0.031	0.00453	<0.001	0.001	0.045	<0.002	0.011	0.004	0.004	0.004	0.004	0.004	0.004	0.004
M.A-219	109	06/04/97	02:00 PM	TM	1.254	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Mineral-Like Process Demonstration (Mineral Hill Water)																		
M.A-300	101	06/04/97	07:00 PM	SP-20	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
M.A-301	100B	06/04/97	07:00 PM	DISS	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
M.A-302	102	06/04/97	07:00 PM	DISS	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
M.A-303	101	06/04/97	07:00 PM	DISS	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
M.A-304	105	06/04/97	07:00 PM	DISS	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
M.A-305	101	06/04/97	07:00 PM	DISS	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
M.A-306	105	06/04/97	07:00 PM	DISS	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
M.A-307	101	06/04/97	02:00 AM	DISS	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
M.A-308	100C	06/04/97	02:00 AM	DISS	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
M.A-309	100C	06/04/97	02:00 AM	DISS	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
M.A-309A	100C	06/04/97	02:00 AM	DISS	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
M.A-310	105	06/04/97	02:00 AM	DISS	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
M.A-311	101	06/04/97	10:00 AM	DISS	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
M.A-312	102	06/04/97	10:00 AM	DISS	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
M.A-313	100C	06/04/97	10:00 AM	DISS	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
M.A-314	105	06/04/97	10:00 AM	DISS	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
M.A-315	101	06/04/97	10:00 AM	DISS	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
M.A-316	100C	06/04/97	08:00 PM	DISS	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
M.A-317	102	06/04/97	02:00 PM	DISS	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Total																		
356.6																		
261.8E																		

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FIELD ID	Sample ID	Date Sampled	Time Sampled	Sample Type	A. (mg/L)	As (µg/L)	Fe (mg/L)	Cd (mg/L)	Co (mg/L)	Cu (mg/L)	Pb (mg/L)	Mn (mg/L)	F ₂ (mg/L)	Zn (mg/L)	Sulfate (mg/L)	TDS (mg/L)	Arsenic Detection Results		
																	Tot As (µg/L)	As (H) (µg/L)	As (M) (µg/L)
Auriferous Absorption Process Low Level Arsenic Demonstration (ASAPROD)																			
RLA1-01	301	08/16/97	06:30 PM	DSS	<0.204	2.279													
RLA1-03	302	08/16/97	06:30 PM	DSS	6.43	0.219													
RLA1-05	303	08/16/97	06:00 PM	DSS		0.24													
RLA1-06	304	08/16/97	06:30 PM	DSS		0.068													
RLA1-07	305	08/16/97	06:30 PM	DSS		0.0273													
RLA1-08	306	08/16/97	06:30 PM	DSS		0.0002													
RLA1-09	307	08/16/97	07:00 PM	DSS		0.0437													
RLA1-10	308	08/16/97	07:44 PM	DSS		0.035													
RLA1-11	309	08/16/97	07:44 PM	DSS		0.221													
RLA1-12	310	08/16/97	06:00 PM	DSS		0.215													
RLA1-13	311	08/16/97	06:31 PM	DSS		0.0003													
RLA1-14	312	08/16/97	06:11 PM	DSS		0.253													
RLA1-15	313	08/16/97	06:00 PM	DSS		0.0495													
RLA1-16	314	08/16/97	06:30 PM	DSS	<0.204	0.0243													
RLA1-18	316	08/16/97	06:32 PM	DSS	<0.204	0.0461													
Alumina Absorption Process Low Level Arsenic Demonstration (ASAPROD)																			
RLA2-01	317	08/16/97	02:00 AM	DSS	<0.204	0.0507													
RLA2-02	318	08/16/97	12:30 AM	Sulfate															
RLA2-03	319	08/16/97	02:00 AM	DSS	0.388	0.005													
RLA2-04	320	08/16/97	12:30 AM	Sulfate															
RLA2-05	321	08/16/97	01:00 AM	DSS		0.391													
RLA2-06	322	08/16/97	01:30 AM	DSS		0.103													
RLA2-07	323	08/16/97	01:30 AM	DSS		0.163													
RLA2-08	324	08/16/97	01:30 AM	DSS		0.243													
RLA2-09	325	08/16/97	02:00 AM	DSS		0.0372													
RLA2-10	326	08/16/97	02:30 AM	DSS		0.0374													
RLA2-11	327	08/16/97	03:00 AM	DSS		0.0513													
RLA2-12	328	08/16/97	03:00 AM	DSS		0.794													
RLA2-13	329	08/16/97	03:30 AM	DSS		0.101													
RLA2-14	330	08/16/97	03:30 AM	DSS		0.276													
RLA2-15	331	08/16/97	04:00 AM	DSS		0.267													
RLA2-16	332	08/16/97	04:30 AM	DSS	<0.204	0.0143													
RLA2-17	333	08/16/97	04:30 AM	DSS	0.264	0.522													
RLA2-19	335	08/16/97	04:30 AM	Sulfate															
Alumina Absorption Process Low Level Arsenic Demonstration (ASAPROD)																			
ALA-01	334	08/16/97	06:00 AM	TSS	<0.02	5.201													
ALA-02	335	08/16/97	06:00 AM	DSS	<0.02	0.261													
ALA-03	336	08/16/97	06:00 AM	TSS															
ALA-04	337	08/16/97	06:00 AM	DSS															
ALA-05	338	08/16/97	06:00 AM	TSS															
ALA-06	339	08/16/97	06:00 AM	DSS															
ALA-07	340	08/16/97	06:00 AM	TSS															
ALA-08	341	08/16/97	06:00 AM	DSS															
ALA-09	342	08/16/97	06:00 AM	Sulfate															
ALA-10	343	08/16/97	06:00 AM	DSS		0.437													
ALA-11	344	08/16/97	06:00 AM	DSS		2.632													
ALA-12	345	08/16/97	06:00 AM	DSS		9.27													
Alumina Absorption Process Low Level Arsenic Demonstration (ASAPROD)																			
ALA-13	346	08/16/97	06:00 AM	TSS															
ALA-14	347	08/16/97	06:00 AM	DSS															
ALA-15	348	08/16/97	06:00 AM	DSS															
ALA-16	349	08/16/97	06:00 AM	DSS															
ALA-17	350	08/16/97	06:00 AM	DSS															
ALA-18	351	08/16/97	06:00 AM	DSS															
ALA-19	352	08/16/97	06:00 AM	DSS															
ALA-20	353	08/16/97	06:00 AM	DSS															
ALA-21	354	08/16/97	06:00 AM	DSS															
ALA-22	355	08/16/97	06:00 AM	DSS															
ALA-23	356	08/16/97	06:00 AM	DSS															
ALA-24	357	08/16/97	06:00 AM	DSS															
ALA-25	358	08/16/97	06:00 AM	DSS															
ALA-26	359	08/16/97	06:00 AM	DSS															
ALA-27	360	08/16/97	06:00 AM	DSS															
ALA-28	361	08/16/97	06:00 AM	DSS															
ALA-29	362	08/16/97	06:00 AM	DSS															
ALA-30	363	08/16/97	06:00 AM	DSS															
ALA-31	364	08/16/97	06:00 AM	DSS															
ALA-32	365	08/16/97	06:00 AM	DSS															
ALA-33	366	08/16/97	06:00 AM	DSS															
ALA-34	367	08/16/97	06:00 AM	DSS															
ALA-35	368	08/16/97	06:00 AM	DSS															
ALA-36	369	08/16/97	06:00 AM	DSS															
ALA-37	370	08/16/97	06:00 AM	DSS															
ALA-38	371	08/16/97	06:00 AM	DSS															
ALA-39	372	08/16/97	06:00 AM	DSS															
ALA-40	373	08/16/97	06:00 AM	DSS															
ALA-41	374	08/16/97	06:00 AM	DSS															
ALA-42	375	08/16/97	06:00 AM	DSS															
ALA-43	376	08/16/97	06:00 AM	DSS															
ALA-44	377	08/16/97	06:00 AM	DSS															
ALA-45	378	08/16/97	06:00 AM	DSS															
ALA-46	379	08/16/97	06:00 AM	DSS															
ALA-47	380	08/16/97	06:00 AM	DSS															
ALA-48	381	08/16/97	06:00 AM	DSS															
ALA-49	382	08/16/97	06:00 AM	DSS															
ALA-50	383	08/16/97	06:00 AM	DSS															
ALA-51	384	08/16/97	06:00 AM	DSS															
ALA-52	385	08/16/97	06:00 AM	DSS															
ALA-53	386	08/16/97	06:00 AM	DSS															
ALA-54	387	08/16/97	06:00 AM	DSS															
ALA-55	388	08/16/97	06:00 AM	DSS															
ALA-56	389	08/16/97	06:00 AM	DSS															
ALA-57	390	08/16/97	06:00 AM	DSS															
ALA-58	391	08/16/97	06:00 AM	DSS															
ALA-59	392	08/16/97	06:00 AM	DSS															
ALA-60	393	08/16/97	06:00 AM	DSS															

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Auraria Absorption Process Low Level Auraria Demonstration (ASABCO)																						
FIELD ID	Sample Port	Sample	Date	Line	Sample Type	A (mg/L)	As (ppb)	Cd (mg/L)	Cr (mg/L)	Cu (mg/L)	Fe (mg/L)	Pb (mg/L)	Mn (mg/L)	P (mg/L)	S (mg/L)	T (mg/L)	Zn (mg/L)	305/60 (mg/L)	TSS (mg/L)	As (III) (ppb)	As (V) (ppb)	Total As (ppb)
A-A-154	201	38/1987	05:00 AM	REC		0.033	9.61	0.197	137.883	7.244	0.83	0.283	13.546									
A-A-154A	201	38/1987	05:00 AM	TSS		0.23	0.063	0.1276	0.060	1302.64	6.653	-0.242	-0.236									
A-A-162	201	38/1987	05:00 AM	TSS		71.404	0.192	0.395	958.48	6.16	0.42	-0.02	30.633									
A-A-162A	202	38/1987	05:00 AM	TSS		73.093	0.198	0.393	958.160	6.019	0.33	0.41	42.619									
A-A-166	201	38/1987	05:00 AM	TSS																		
A-A-167	202	38/1987	05:00 AM	TSS																		
A-A-168	202	38/1987	05:00 AM	TSS																		
A-A-171	201	38/1987	05:00 AM	TSS																		
A-A-172	202	38/1987	05:00 AM	TSS																		
A-A-172A	201	38/1987	05:00 AM	TSS																		
A-A-174	202	38/1987	05:00 AM	TSS																		
Auraria Absorption Process Low Level Auraria Demonstration (ASABCO)																						
P-A3-01	305	08/1987	12:00 PM																			
P-A3-02	201	08/1987	03:00 PM																			
P-A3-101	201	08/1987	03:00 PM																			
P-A3-103A	201	08/1987	03:00 PM																			
P-A3-101	205	08/1987	03:00 PM																			
P-A3-102A	202	08/1987	03:00 PM																			
P-A3-103	202	08/1987	03:12 PM																			
P-A3-108	202	08/1987	03:40 PM																			
P-A3-109	202	08/1987	03:40 PM																			
P-A3-110	201	08/1987	04:00 PM																			
P-A3-111	201	08/1987	04:00 PM																			
P-A3-112	201	08/1987	04:00 PM																			
P-A3-113	202	08/1987	04:00 PM																			
P-A3-114	202	08/1987	04:00 PM																			
P-A3-115	201	08/1987	05:00 PM																			
P-A3-116	201	08/1987	05:00 PM																			
P-A3-117	201	08/1987	05:00 PM																			
P-A3-118	202	08/1987	05:00 PM																			
P-A3-119	202	08/1987	05:00 PM																			
P-A3-120	201	08/1987	05:00 PM																			
P-A3-121	202	08/1987	05:00 PM																			
P-A3-122	202	08/1987	05:00 PM																			
P-A3-123	201	08/1987	05:00 PM																			
P-A3-124	202	08/1987	05:00 PM																			
P-A3-125	202	08/1987	05:00 PM																			
P-A3-126	201	08/1987	05:00 PM																			
P-A3-127	201	08/1987	05:00 PM																			
P-A3-128	201	08/1987	05:00 PM																			
P-A3-129	201	08/1987	05:00 PM																			
P-A3-130	202	08/1987	05:00 PM																			
P-A3-131	202	08/1987	05:00 PM																			
P-A3-132	201	08/1987	05:00 PM																			
P-A3-133	201	08/1987	05:00 PM																			
P-A3-134	202	08/1987	05:00 PM																			
P-A3-135	202	08/1987	05:00 PM																			

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IRON ADSORPTION TEST DATA

Arsenic Speciation Results

FIELD	Sample	Date	Time	Sample	As (ICP)	As (AA)	Cd	Cu	Fe	Pb	P	Zn	As (III)	As (V)
LOC	Port	Sampled	Sampled	Type	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(ug/L)	(ug/L)
Iron Coprecipitation Process Demonstration (Mineral Hill Water)														
ILM-100-A	203A	09/02/97	12:15 AM	DISS	0.058	0.02742								
ILM-100-B	203A	09/02/97	12:30 AM	DISS	0.030	0.01704								
ILM-100-C	203A	09/02/97	12:45 AM	DISS	0.051	0.02018								
ILM-100-D	203A	09/02/97	01:00 AM	DISS	0.041	0.02153								
ILM-100-E	203A	09/02/97	01:15 AM	DISS	0.053	0.02228								
ILM-100-F	201	09/02/97	03:05 PM	DISS	0.419				0.155					
ILM-100-G	202	09/02/97	03:05 PM	DISS	0.02	0.00892			0.127					
ILM-100-H	202	09/02/97	03:20 PM	TM	0.37				6.316					
ILM-101-A	202	09/02/97	06:10 PM	DISS		0.00596								
ILM-101-B	202	09/02/97	06:10 PM	SPEC								323.1		336.05
ILM-101-C	202	09/02/97	06:10 PM											
ILM-101-D	202	09/02/97	06:10 PM											
ILM-101	202	09/02/97	06:20 PM	DISS	-0.005	0.00734			0.047					
ILM-102	204	09/02/97	06:20 PM	DISS	0.024	0.02837			<0.024					
ILM-103	204	09/02/97	06:20 PM	DISS	-0.036	<0.001								
ILM-104	201	09/02/97	06:20 PM	DISS	0.398									
ILM-105	203	09/02/97	06:20 PM	DISS	0.026	0.02261								
ILM-106A	201	09/03/97	01:20 AM	DISS	0.392									
ILM-106B	202	09/03/97	01:20 AM	DISS	0.01	0.0058								
ILM-106C	203	09/03/97	01:20 AM	DISS	0.073									
ILM-106D	204	09/03/97	01:20 AM	DISS	0.04	0.0319								
ILM-108	201	09/03/97	09:20 AM	DISS	0.384									
ILM-109	206	09/03/97	09:20 AM	DISS	0.017	0.03949								
ILM-110	201	09/03/97	05:30 PM	DISS	0.363									
ILM-111	201	09/03/97	05:30 PM	DISS	0.379									
ILM-112	206	09/03/97	05:30 PM	DISS	0.056	0.05403								
ILM-113	202	09/03/97	05:30 PM	DISS	0.032	0.0107			0.031					
ILM-114	204	09/03/97	05:30 PM	DISS	0.06	0.03657								
ILM-115A	201	09/04/97	01:20 AM	DISS	0.385									
ILM-115B	202	09/04/97	01:20 AM	DISS	0.026	0.01841			<0.024					
ILM-115C	202	09/04/97	01:20 AM	TM	0.397				4.567					
ILM-115D	203	09/04/97	01:20 AM	DISS	0.040	0.04811								
ILM-115E	204	09/04/97	01:20 AM	DISS	0.04	0.04034								
ILM-116	206	09/04/97	01:20 AM	DISS	0.071	0.05232								
ILM-117A	201	09/04/97	09:30 AM	DISS	0.366									
ILM-117B	202	09/04/97	09:30 AM	DISS	0.011	0.01219			<0.024					

Asenic Speciation Results

FIELD ID	Sample Port	Date Sampled	Time Sampled	Sample Type	As (ICP) (mg/L)	As (AA) (mg/L)	Cd (mg/L)	Cu (mg/L)	Fe (mg/L)	Pb (mg/L)	P (mg/L)	Zn (mg/L)	As (III) (ug/L)	As (V) (ug/L)
ILM-118	206	09/04/97	09:30 AM	DISS	0.044	0.0459								
ILM-119	201	09/05/97	05:30 PM	TREC	0.377		0.009	0.007	0.141	<0.02	0.044	0.031		
ILM-119A	201	09/04/97	05:30 PM	DISS	0.386		0.008	0.004	<0.024	<0.02	0.045	0.032		
ILM-120	206	09/05/97	05:30 PM	TREC	0.114			<0.003	0.549	<0.02	<0.03	<0.009		
ILM-120A	206	09/04/97	05:30 PM	DISS	0.049	0.07311	<0.004	<0.003	<0.024		0.062	<0.009		
ILM-121	201	09/04/97	05:30 PM	DISS	0.38									
ILM-122	206	09/04/97	05:30 PM	DISS	0.067	0.06456								
ILM-123	206	09/04/97	05:30 PM	DISS	-0.022	<0.001								
ILM-124A	202	09/04/97	05:30 PM	DISS	0.006	0.01603			<0.024					
ILM-124B	202	09/04/97	05:30 PM	TREC	0.022	0.01646			0.027					
ILM-125	204	09/04/97	05:30 PM	DISS	0.045	0.07113			<0.024					
ILM-126A	202	09/04/97	05:30 PM	TREC	0.392				2.776					
ILM-126B	202	09/04/97	12:00 AM	DISS	0.186									
ILM-126C	202	09/04/97	12:00 AM	DISS	0.077	0.09562								
ILM-126D	202	09/04/97	12:00 AM	DISS	0.096	0.10491								
ILM-126E	202	09/04/97	12:00 AM	DISS	0.082	0.09738								
ILM-126F	202	09/04/97	12:00 AM	DISS	0.072	0.09411								
ILM-126	202	09/04/97	03:30 AM	DISS	0.079	0.08376								
ILM-129	204	09/05/97	03:30 AM	DISS	0.075	0.07863								
ILM-130	202	09/05/97	03:30 PM	TREC	0.374				2.454					
ILM-130A	202	09/05/97	03:30 PM	DISS	0.074	0.10728			<0.024					
ILM-131	203	09/05/97	03:30 PM	DISS	0.071	0.09447								
ILM-131A	204	09/05/97	03:30 PM	DISS	0.097	0.08991								
ILM-132	204	09/05/97	03:30 PM	DISS	-0.017	<0.001								
ILM-1120A	202	09/05/97	07:30 AM	DISS	0.084	0.0849								
ILM-1126B	203	09/05/97	07:30 AM	DISS	0.095	0.07070								
ILM-1129	204	09/05/97	07:30 AM	DISS	0.072	0.07455								
ILM-2128A	202	09/05/97	12:00 PM	DISS	0.106									
ILM-2128B	203	09/05/97	12:00 PM	DISS	0.095	0.09786								
ILM-2129	204	09/05/97	12:00 PM	DISS	0.084	0.09501								
ILM-2130	201	09/05/97	12:00 PM	DISS	0.315									
Fe-133 SOI N		15/05/97	12:00 AM	TREC										2087.2

Iron Coprecipitation Process Demonstration (Mineral Hill Water)

BTFE 101A	201	09/08/97	01:01 PM	DISS	0.075	0.07533
BTFE 101B	201	09/08/97	01:02 PM	DISS	0.036	0.02409

Arsenic Speciation Results

FIELD ID	Sample Port	Date Sampled	Time Sampled	Sample Type	As		Cd	Cu	Fe	Pb	P	Zn	As		As (V)
					(ICP) (mg/L)	(AA) (mg/L)							(ug/L)	(ug/L)	
BTFE 101E	201	09/08/97	02:00 PM	DISS	-0.003	0.00571									
BTFE 101F	201	09/08/97	02:00 PM	TM	0.342				6.269						
BTFE 102A	202	09/08/97	01:01 PM	DISS	0.026	0.03288									
BTFE 102B	202	09/08/97	01:02 PM	DISS	0.007	0.01403									
BTFE 102C	202	09/08/97	01:05 PM	DISS	-0.013	0.00942									
BTFE 102D	202	09/08/97	01:15 PM	DISS	-0.044	0.00536									
BTFE 102E	202	09/08/97	02:00 PM	DISS	-0.05	0.00165			3.048						
BTFE 102F	202	09/08/97	02:00 PM	TM	0.339										
BTFE 103A	203	09/08/97	01:01 PM	DISS	-0.001	0.01027									
BTFE 103B	203	09/08/97	01:02 PM	DISS	-0.032	0.00504									
BTFE 103C	203	09/08/97	01:05 PM	DISS	-0.043	0.0054									
BTFE 103D	203	09/08/97	01:15 PM	DISS	-0.024	0.00272									
BTFE 103E	203	09/08/97	02:00 PM	DISS	0.352				0.354						
BTFE 103F	203	09/08/97	02:00 PM	TM	-0.028	0.00141									
BTFE 201A	201	09/08/97	03:15 PM	DISS	0.223										
BTFE 201B	201	09/08/97	03:16 PM	DISS	0.208										
BTFE 201C	201	09/08/97	03:05 PM	DISS	0.186										
BTFE 201D	201	09/08/97	03:15 PM	DISS	0.208										
BTFE 201E	201	09/08/97	04:15 PM	DISS	0.168										
BTFE 201F	201	09/08/97	04:15 PM	TM	0.428				1.887						
BTFE 202A	202	09/08/97	03:15 PM	DISS	0.089	0.0546									
BTFE 202B	202	09/08/97	03:16 PM	DISS	0.051	0.04351									
BTFE 202C	202	09/08/97	03:05 PM	DISS	0.068	0.04079									
BTFE 202D	202	09/08/97	03:15 PM	DISS	0.035	0.0316									
BTFE 202E	202	09/08/97	04:15 PM	DISS	0.007	0.02599									
BTFE 202F	202	09/08/97	04:15 PM	TM	0.368				1.615						
BTFE 203A	203	09/08/97	03:15 PM	DISS	0.044	0.01833									
BTFE 203B	203	09/08/97	03:16 PM	DISS	0.006	0.01516									
BTFE 203C	203	09/08/97	03:05 PM	DISS	0.039	0.01397									
BTFE 203D	203	09/08/97	03:15 PM	DISS	-0.002	0.01295									
BTFE 203E	203	09/08/97	04:15 PM	DISS	0	0.01126									
BTFE 203F	203	09/08/97	04:15 PM	TM	0.42				1.579						

